Hydrodynamic Pathways in a Mature Constructed Wetland

by

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Hydrodynamic Pathways in a Mature Constructed Wetland

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in partial fulfillment of the requirements
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Abstract

One of the low-cost options for the treatment of agricultural wastewaters is the use of constructed wetlands. In order to better understand the physical mechanism at work within a mature constructed wetland, a study was conducted at the Dignard Wetland in Ontario, Canada. Throughout the course of a two-year study, percent removals of BOD₅ (45%), ammonia (56%), nitrates (8%), phosphorous (33%), and TKN (67%) were monitored. The movement of a tracer was also monitored through the two marsh cells of the constructed wetland. The kinetic rate constants were calculated as 5.7 m/y for BOD₅, 7.5 m/yr for ammonia, and 3.3 m/yr for TKN, which varied greatly (26-75%) from the values suggest in related literature, which are based on young constructed wetlands. The sedimentation pattern and vegetation density were monitored and correlated to the flow with the wetland cells, to determine that sediments were removed through both settling and filtration.

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CHAPTER 1

INTRODUCTION

The agricultural industry is important to the economy of Canada. As the demand for livestock products increases, so does the size of farms and the wastewater production from herds. Increased wastewater production is a topic of significant public concern.

The public concern with respect to wastewater production results from various factors. There are fewer active farmers currently working in eastern Ontario than in years past, but the demand for livestock products is increasing (Robson, 1999). This creates a situation where there are fewer farms, but the farms house more livestock units (LU). These farmers are expanding their agri-businesses into “mega farms” which have become so large that they cannot be ignored. At the same time, more people are moving to rural areas, trying to escape large city congestion, but bring with them a “big city attitude”. People that have lived in rural areas for the majority of their lives have come to understand the requirements of farming, as well as the noise and odours associated with them. These people also understand that the farms will expand, and that they will have to accommodate this. The “big city attitude” brings along with it the resistance to the change, as well as the outrage with respect to some elements of farming realities such as appearance, odours, noise and potential pollution, to name a few.

While the appearance and noise of farms are problems that cannot be fixed (without significant technological advances), the odour and pollution problems can be remediated. Many odour and pollution issues can be associated with the nutrients in the animal wastes. These nutrients can be transported to local rivers, streams and groundwater aquifers in the area. Nutrient management plans are put in place to reduce the pollution associated with the wastes. Currently, the province of Ontario is developing

standards for the treatment of agricultural wastes, where farms will be required to account for and treat any wastewater that will be discharged into the surrounding areas.

There are many different methods of treating the rural wastewater, which include: solid-liquid separation (a manure management option), aeration (reduction of ammonia and BOD₅ concentrations), digestion (odour reduction, and pathogen destruction with the advantage of methane production as an energy source), and composting (volume reduction with a high nutrient fertilizer as a by-product). Some of these treatment options can be very high in cost (\$15 per head of cattle, \$10 per pig) (Robson, 1999). Most of the practices involve intensive labour, which is much more than is already available at often-understaffed farms. Since farmers have no control over the price of the products that are produced, they often cannot recuperate the costs associated with the treatment technology, or the added labour.

Often convenient solutions for farmers are passive treatment systems. These systems can be easily operated, and the capital, as well as the operation and maintenance costs, will be lower than more active treatment methods. Systems can be setup such that all of the components are electronically controlled and there is only a need to verify the operation, or the control can be setup such that only a pump needs to be started and stopped at regular intervals (a task that will not take much labour). Constructed wetlands are an excellent option for nutrient management on farms. They are easily operated, relatively inexpensive, when the required land is available, and as an added bonus, they typically attract wildlife to the area.

1.1 OBJECTIVES

For as many years as wetlands have been in use, people have studied them to better understand the processes at work. The goal is to design more efficient systems that require less overall land area. In the past, tracer studies have been conducted (Kadlec, 1994; Schmid et al., 2004; Bowmer, 1987) to analyze actual wetland retention times, but there has not been much work at analyzing flow patterns within the wetland cells. Many of the parameters that are currently used to design wetlands are estimated from large monitoring databases of wetlands which have been studied in the first two or three years of operation, with little data from mature systems (systems operating for more than five years). When a system is first built, the vegetation that is planted is generally distributed evenly throughout the cell, with controlled types of vegetation planted, there are no sediments on the bottoms of the cells, phosphorous adsorption sites are available throughout the soil, bacterial populations are immature, and there is a minimal animal and insect larval activity within the cells. During the years of wetland operation, the bacterial cultures mature. Vegetation propagates in some area of the cells and stops growing in others, resulting in uneven vegetation of the cell. As well, other local plant species will invade the cell with time. Sediments start to deposit within the wetlands cells, creating preferential flow channels. Phosphorous adsorption sites begin to become depleted and blocked by the buildup of sediments and bacteria, reducing the phosphorous removal potential of the system. Animals begin to build nests in the vegetation of the cells, and insects begin to lay eggs in the wastewater, the resulting larvae can begin to prey on the bacteria of the system, reducing the efficiency of bacterial treatment.

The purpose of this study was to understand the flow pathways within a mature (operating for nine years) constructed wetland treating dairy cattle manure runoff and milkhous washwater over two operating seasons, and to determine if preferential pathways have been established due to plant growth and uneven settling of solids. This study also aimed to examine the inlet and outlet characteristics of the wetland to determine if different flow conditions would result in different treatment capacities, as well as determining the applicability of literature design nutrient removal rate constants, and existing design models, to the wetland employed in this study.

1.2 SCOPE OF STUDY

In order to attain the study objectives, the work that was undertaken during the two-year study included the following:

- Three separate tracer studies to understand the flow dynamics within the constructed wetland;
- Two years of water column sampling and analysis to determine the treatment efficiency of each wetland cell;
- One year of pore water sampling and analysis within the sediment zones to assist in the determination of the treatment efficiency of each wetland cell;
- Mapping of sediments and vegetation of the first vegetated wetland cell to determine sedimentation patterns; and,
- Field and lab analysis of the water samples.

1.3 SAMPLE SITE – DIGNARD WETLAND, EMBRUN, ONTARIO, CANADA

The constructed wetland used in this study was constructed on the Dignard dairy farm in 1994 and was designed to treat the wastewater from a herd of 190 livestock units. The dairy operation produces three types of wastewaters: washwater from the cleaning of milkhouse equipment, stormwater runoff from the cattle exercise yard and liquid runoff from the solid manure pile. Prior to the construction of the wetland, the liquid manure runoff and the milkhouse washwater were stored in a lagoon and periodically spread onto cropland, while the runoff from the exercise yard was not collected. The farmer was searching for a method to treat the liquid wastewater, which did not require application on to cropland.

The constructed wetland was designed such that the pre-existing lagoon continued to be used to collect the runoff from the solid manure pile. The manure pile runoff and milkhouse washwater was pumped into a facultative pond where it would mix with the runoff from the exercise yard, which was collected using an overland flow system. The effluent from the facultative pond was then pumped into a marsh-pond-marsh constructed wetland system. A vegetated filter, which used barley as the cover crop, was used as a final polishing stage for the constructed wetland effluent.

CHAPTER 2

BACKGROUND

Natural wetlands have been employed in the mitigation of wastewaters for many years. Wetlands can remove pathogens, neutralize pH, and decrease concentrations of harmful chemicals and pollutants. Constructed wetland treatment has been a topic of research and development since the late 1970s. Constructed wetlands, which are designed to imitate natural wetlands, are currently used to treat many pollutant streams, including: leachate from municipal solid waste (MSW), acid rock drainage (ARD), landfill leachate, urban runoff, as well as wastewater streams from photo developing labs, textile plants, rendering plants, pulp mills and refineries (Watson and Hobson, 1991).

Passive treatment systems, such as constructed wetlands, offer low-cost, easily operated and efficient treatment alternatives. Other active treatment systems for wastewater streams involve the addition of chemicals or mechanical works to produce an effluent that meets regulatory discharge standards. The costs associated with these types of systems can be high. The chemical additives must be purchased, and since they are used up in the process, they must be constantly replenished. The equipment that is involved in the different steps of the treatment process must also be purchased, and maintained. The design of the facility must include extra flow channels in each step of the treatment process so that some channels can be taken off-line for maintenance purposes, while maintaining treatment objectives. On-site operation and maintenance staff must also be employed. The costs associated with a constructed wetland include: the purchase of the land, labor to build the wetland, and staffing for the monitoring of the influent and effluent to ensure that the treated effluent complies with discharge guidelines.

Typically, constructed wetlands do not require frequent maintenance of machinery, since the number of mechanical systems is generally minimal. The absence of chemical addition means that there are no employees required to handle chemical stores. The only maintenance required is the periodic testing of the influent and effluent to ensure compliance with discharge criteria. Wetlands can also be designed to treat wastewater streams as efficiently as active treatment systems. The reduced amount of maintenance, ease of operation and treatment efficiency demonstrate the advantage of passive treatment systems as a convenient treatment alternative that farmers can utilize as a nutrient management option.

2.1 TYPES OF CONSTRUCTED WETLANDS

There are two different types of constructed wetlands in operation, free water surface (FWS) and subsurface flow (SSF) wetlands (Kadlec and Knight, 1996). A free water surface wetland was the focus of this study. FWS wetlands are systems where the flow of the wastewater is above the sediment zone. These wetlands can remain unvegetated (pond cells) or can be planted with emergent vegetation (reeds, sedges, grasses), or floating vegetation (duckweed). SSF wetlands are systems where the wastewater flows through a porous media. These systems can remain unvegetated or be planted with similar plants as the emergent vegetation for FWS wetlands.

There are a number of factors involved in the design of wetlands. One must assess the objectives of the treatment, the nature of the expected wastewater stream, the constituents that will require treatment, the criteria or guidelines that will govern effluent standards and any safety factors involved. The type of treatment that is to be carried out by the wetland is also a factor. Wetlands can be used as a primary treatment method.

employed as a polishing step after a more active treatment, or be part of a larger system where the wetland effluent is expected to go through subsequent processes. The type of system, surface or subsurface, and the configuration of the system, channels in parallel or series, must also be considered.

Surface wetlands are designed to sustain life as well as convey water flow. The soil has to be a suitable medium for plant growth, as well as stable enough that it will not erode. There must be a liner or low permeability barrier soil that will prevent leaching through the soil. Water depth is another issue, if the water is too deep, wind driven aeration will not provide oxygen to greater depths, and these areas will not be able to support aerobic bacteria. The minimum and maximum depths of flow also affect the choice of plants for the wetland. Flow channels should also generally be setup to induce a plug flow through the wetland cells (Kadlec and Knight, 1996).

There are many factors that govern the treatment efficiency of the wetland. The hydraulic loading, ambient and water temperatures, flora and fauna within the wetland, types of pollutants, and exposure time are just some of the parameters involved (Kadlec and Knight, 1996). Uncertainties, such as fluctuations in design flows, also have an impact. The volumes of flow, as well as the concentration of pollutants, can change on a daily basis and rainfall, drought, etc. are of great importance. Hydraulic overloads, rainfall events, and snowmelt increase the flow into the wetland, diluting the wastewater stream, which can interfere with processes within the wetland that are more efficient with more concentrated streams, as well as increasing the flow rate and reducing the residence time within the wetland cells (Chazarence *et al.*, 2003). These problems must be overcome to create an efficient treatment system.

Since wetland treatment has not been studied over an extended period of time, there are some uncertainties associated with the life expectancy of the treatment system. Each wetland must be periodically tested to establish whether the efficiency remains consistent with time.

2.2 WASTEWATER TREATMENT

In recent years, farmers have had growing concerns with respect to wastewater nutrient management. The large volumes of wastewater from their livestock and production facilities must be treated to minimize the potential contamination of receiving waters (Hill *et al.*, 2000). This can be achieved through the use of natural systems such as wetlands. To protect the wetland system, the wastewater should be pre-treated to reduce the nutrient loads to manageable levels. The engineered natural treatment systems can be classified into two categories, which depend upon the desired treatment objectives:

- 1) Primary treatment includes: anaerobic lagoons, facultative ponds, or other systems that are designed to handle large nutrient loading.
- 2) Secondary treatment includes: wetland polishing of low nutrient lagoon and pond effluents.

Factors that need to be considered in the design of these wetlands are the discharge limits, and required safety factors. Discharge limits may be regulated by municipalities or government agencies with the goal of public and safety, while safety factors based on the size of the wetland must also be specified to ensure that large rainfall events will not cause the wetland to overflow, which would allow untreated wastewater to enter directly into a receiving body of water.

2.2.1 Expected Streams

Wastewater streams that can discharge to wetlands are highly variable, and the source greatly impacts the composition and flow of the wastewater. Different livestock operations generate wastewaters with different nutrient characteristics (based on the diet of the animals) (McKee and Brooks, 1994). Farms usually collect the wastewater in piles and allow rainwater to carry the wastewater to the wetlands. Thus, precipitation patterns of the area will change the concentrations of the nutrients in the wastewater.

The influent wastewater can be separated into different categories. The Council for Environmental Quality had noted three classes of sewage based upon the concentrations of phosphorous and BOD₅. With regards to phosphorous, the council rates concentrations of less than 2mg/L as weak, 5mg/L as medium, and 10 mg/L as strong. BOD₅ ranges are much higher, a weak sewage will have concentrations of less than 100 mg/L, 200 mg/L will rate as medium and 450 mg/L as a strong sewage. Nitrogen, usually reported as Total Kjeldahl Nitrogen (TKN), has been found in agricultural wastewater to have concentrations ranging from 10 to 183mg/L. The bacteria in agricultural wastewater have been found to range from 10^5 to 10^7 /100ml in terms of total coliform, and 5×10^4 to 10^6 /100ml for fecal coliform (McKee *et al.*, 1994).

2.2.2 Primary Treatment of Wastewater for Wetland Systems

Primary treatment of wastewater generally takes place in anaerobic lagoons and facultative ponds. These systems are designed to remove high nutrient concentrations from the system in a short period of time. Treatment in these ponds is efficient, while there are high concentrations of wastewater constituents, but as concentrations of the constituents decrease, the treatment efficiency typically decreases as well.

Anaerobic lagoons receive high nutrient loads, often sufficient to deplete all of the dissolved oxygen in the system. The high surface area and low velocity of lagoons are ideal for the removal of suspended solids. As the solids settle, other constituents in the wastewater bind to the settling particles and are also removed. The remainder of the reduction in constituent concentrations results from the anaerobic treatment of the wastewater.

Facultative ponds receive a wastewater stream with a weaker nutrient loading than anaerobic lagoons. The surface area of the pond is large enough, and the nutrient concentrations low enough, to allow shallow depths of the pond to function under aerobic conditions. The settling of solids brings more of the organic fraction to the depths of the pond where anaerobic processes will be prevalent. Ponds achieve efficient treatment due to these two distinct effective treatment zones.

2.2.3 Secondary Treatment (Constructed Wetlands)

Standard free water surface wetland designs involve a set of channels with flow controlled by exit structures such as weirs. Another option for the layout of a wetland would be a system where the flow passes through a marsh stage. The water then continues to a pond for further settling of the solids and aeration of the wastewater, with a final marsh system acting as a polishing stage (Kadlec and Knight, 1996).

Design criteria for optimum treatment are detention times of 5-14 days to allow for the settling of suspended solids, as well as the establishment of bacterial and chemical reaction kinetics. The maximum BOD loading rate should be 80 kg/ha-day (Kirby, 2002), to maintain aerobic conditions within the system. The water depths within the wetland should be between 0.1 and 0.8 m (Kirby, 2002) to ensure that wind-induced aeration can

reach the lower depths of wetland. If the depth were shallower, the wetlands would run a risk of drying out, which could result in a loss of vegetation. If the flow were too high, the soil and sediments would get carried off in the flow and solids would not be able to settle out (Kirby, 2002).

2.2.4 Soil

The soil of the wetland can also have an effect on treatment, by adsorbing some of the contaminants. The effectiveness of the soil adsorption of phosphorous in the wastewater stream is dependant upon the type of soil, the density of the soil, its permeability, depth, slope of the bed, water level and the hydraulic gradients within the system. Clogging of the pore space within the soil can lead to a reduction in adsorption processes. Bacteria from the wastewater typically mix with the bacteria in the wetland. These bacteria grow quickly in the nutrient rich media to form large flocs. These flocs then settle and reach the sediment layer. Once the soil is covered and the aerobic bacteria have depleted the dissolved oxygen, anaerobic bacteria start to form a slime layer over the settled matter. This slime layer resists decomposition and deterioration, which could create a barrier between the soil and the wastewater and reduce the efficiency of the wetland (Brooks, 1988).

2.2.5 Treatment Mechanisms in Constructed Wetland Systems

Biological, physical and chemical treatment processes occur within the wetland cells. Table 2.1 outlines the processes at work in a FWS wetland for the removal of various constituents.

Table 2.1 Pollutant Removal Processes (adapted from DLWC, 1998)

Pollutant	Removal Mechanisms
Organic Material (measured as BOD)	biological degradation, sedimentation, microbial uptake
Organic Contaminants (e.g. pesticides)	adsorption, volatilization, photolysis, biotic/abiotic degradation
Suspended Solids	sedimentation, filtration
Nitrogen	sedimentation, ammonification, nitrification/denitrification, microbial uptake, plant uptake, volatilization
Phosphorous	sedimentation, filtration, adsorption, plant & microbial uptake
Pathogens	natural die-off, sedimentation, filtration, predation, UV degradation, adsorption
Heavy Metals	sedimentation, adsorption, plant uptake

2.2.5.1 Nitrogen Removal

The contaminant of greatest concern in agricultural wastewater is nitrogen, which is often evaluated as Total Kjeldahl Nitrogen (TKN) and a measure of organic nitrogen species and ammonia. Wetland treatment can reduce nitrogen concentrations through plant and bacterial activities. Ammonia nitrification (ammonia being oxidized to nitrate) is performed near the nodules at the roots of the plant structures by nitrifying bacteria: *Nitrosomas* and *Nitrobacter*, respectively. Strict aerobic bacteria, which consume oxygen to oxidize the ammonia to nitrite, control this process; the nitrite is then subsequently oxidized further to nitrate. Nitrate can then be reduced to free nitrogen by denitrifying bacteria. This process begins when the dissolved oxygen in the system is reduced to zero, bacteria then use the oxygen in the nitrate molecule as an electron acceptor. This process will only occur in the presence of available organic carbon under anoxic conditions (Kadlec and Knight, 1996).

2.2.5.2 Phosphorous Removal

The mechanisms of phosphorous removal in wetlands include: adsorption, complexation, plant uptake, immobilization onto organic matter and chemical precipitation.

The main method of phosphorous removal is adsorption onto the soil. Dispersible soils reduce the efficiency of the phosphorous removal, while sandy soil tends to increase the removal (Begg *et al.*, 2001). The highest removal of phosphorous is generally observed in wetlands lined with clays rich in iron, aluminum or calcium due to the phosphorous adsorption potential of these sites (Watson and Hobson, 1991). On average, the removal efficiency of phosphorous in a wetland is above 87% (Reddy *et al.*, 2001). Vegetation in the wetland will uptake small amounts of phosphorous through their root zone, and as these plants die and decompose, the phosphorous will be reintroduced into the system.

2.2.5.3 BOD₅ Removal

In a wetland, there are two methods of BOD₅ removal. Larger organics are removed by filtration and settling, while the remaining are removed through microbial activity. In tests involving wetlands with and without vegetation, BOD removal was found to be similar (Hench *et al.*, 2003), indicating limited plant involvement in BOD removal.

Since aerobic microbial activity is involved in BOD₅ removal, dissolved oxygen is required. Aeration can be achieved through wind in shallower wetlands, or hydraulically induced turbulence. Mechanical aerators can also be used, but these would involve a more active approach to the design of the system, leading to increased

operational costs. Covers placed on the system, such as plant overgrowths, or ice in the colder months will block any wind-induced aeration and the system may become anaerobic.

The BOD₅ removal efficiencies of the system are increased when the wetland is mature, as there are more established bacterial colonies to remove the BOD₅. Higher organic loading will also generally increase the efficiency, since there will be a greater quantity of organic substrate to feed the bacteria. If the organic loading is too high, however, the dissolved oxygen will not be available in sufficient quantity to sustain the degradation of the organic material, and this will cause aerobic bacteria to become less active, consequently decreasing the BOD₅ removal (Watson and Hobson, 1991). If the wetland is designed adequately, BOD removals of over 90% can be achieved (Merlin *et al.*, 2002).

2.2.5.4 Suspended Solids Removal

Suspended solids within the wastewater must be removed through filtration and settling. The detention time must allow for the settling of coarse to medium sized particles in the basins, while the plants and the soil can filter smaller particles. Fecal coliform, as well as nitrogen and phosphorous tend to be associated with the smaller fraction of suspended solids, and the removal of these solids could, consequently, result in the removal of some of those contaminants (Watson and Hobson, 1991).

The removal efficiency related to suspended solids varies depending on the design of the system. A system with dense plant life can act as a better filter for smaller particles, whereas a system with sparse plant growth will not remove many of the smaller particles. The effluent from the wetland could also pass through a filter that will remove some of the solids.

2.2.5.5 Pathogen Removal

The removal of pathogens and bacteria in a wetland is crucial. If bacteria exit the wetland system in high concentrations, the bacteria could potentially impact the receiving water body, and ultimately, the health of the public. Bacteria are removed from the water through chemical reactions, radiation, sedimentation, filtration and predation by zooplankton. These removal processes require an adequate retention time for the destruction of bacteria (Watson and Hobson, 1991).

2.2.6 Design Equations

There are three main model equations that have been developed to describe the removal rates of contaminants within FWS wetlands: Crites and Tchobanoglous; Reed, Crites and Middlebrooks; and Kadlec and Knight. These models were defined using a database containing monitoring information from many constructed wetlands, most of which contained data for the first three years of operation (young wetlands). The database of wetlands was used to determine which reactor models best described the treatment processes occurring within wetland the cells, and suggested parameter values and temperature correction factor. The wetlands in the database, mainly treated domestic wastewater, however, in 1997 the Gulf of Mexico program determined the parameter

value for the Kadlec and Knight model with respect to higher concentration agricultural wastewaters (CH2MHill and Payne, 1997).

The Crites and Tchobanoglous model (Crites and Tchobanoglous, 1998) assumes that a wetland acts as four completely stirred tank reactors (CSTR) in series. This assumption is used to account for the dispersion of the wastewater as well as the preferential flow pathways within the wetland cells. This equation is only applicable to describe BOD₅ removal.

$$t = \frac{V}{Q} = \left[\frac{1}{(C_n/C_o)^{1/4}} - 1 \right] \times \frac{4}{k_0} \quad (2-1)$$

Where:

- t is the detention time (days)
- V is the volume of the treatment system (m³)
- Q is the flow rate of the wastewater stream (m³/d)
- C_n is the effluent BOD₅ concentration (mg/L)
- C_o is the influent BOD₅ concentration (mg/L)
- k_o is the overall BOD₅ removal constant (days⁻¹)

The value used for k_o (1.01 d⁻¹ for 20°C) must be corrected using Equation 2-2 for the coldest temperature expected during the operation of the system.

$$\frac{k_2}{k_1} = \theta^{(T_2 - T_1)} \quad (2-2)$$

Where:

- k_1 is the BOD₅ removal constant at temperature T_1 (days⁻¹)
- k_2 is the BOD₅ removal constant at temperature T_2 (days⁻¹)
- θ is the temperature correction factor
(1.02-1.06 is recommended)
- T_1 is the operating temperature T_1 (°C)
- T_2 is typically 20°C

The second method of wetland sizing is the Reed, Crites and Middlebrooks model (Reed *et al.*, 1995). This method is based on first order reaction kinetics in a plug flow reactor. The model is applicable to those pollutants that are primarily removed via biological processes (BOD₅, NH₃, and NO₃⁻). The Crites and Tchobanoglous method recommends that the Reed, Crites and Middlebrooks model be used for both nitrogen and TSS removal equations (Wallace, 2003). The size of the wetland can be determined using equation (2-3).

$$A = \frac{Q_{ave} \ln(C_i/C_e)}{K_{v,T} \times d_w} \quad (2-3)$$

- Where:
- A is the surface area of the Wetland (m²)
 - Q_{ave} is the average flow rate (Q_{in}/Q_{out}) (m³/d)
 - K_{v,T} is the first order rate constant at temperature T °C (days⁻¹)
 - d_w is the depth of the wetland cell (m)
 - C_e is the effluent BOD₅ concentration (mg/L) for BOD₅ removal
 - C_e is the effluent ammonia concentration (mg/L) for nitrification
 - C_e is the effluent nitrate concentration (mg/L) for denitrification
 - C_i is the influent BOD₅ concentration (mg/L) for BOD₅ removal
 - C_i is the influent TKN concentration (mg/L) for denitrification
 - C_i is the influent nitrate concentration (mg/L) for denitrification

The rate constant can be determined for the varying temperatures in the wetland using Equation (2-2) with the values of k_{v,20} and θ from Table 2.2.

Table 2.2 Typical Reed Kinetic Rate Constants (DLWC, 1998)

Parameter	k _{v,20}	θ
BOD ₅	0.678	1.06
Nitrification (NH ₃ removal)	0.2187	1.048
Denitrification (NO ₃ ⁻ removal)	1.0	1.15

The removal of TSS is not considered a critical component of wetland sizing in the Reed, Crites and Middlebrooks model. A removal equation for TSS (Equation 2-4) has been proposed from existing FWS data (DLWC, 1998).

$$C_e = C_i [0.1139 + 0.00213(HLR)] \quad (2-4)$$

Where: C_e is the effluent TSS concentration (mg/L)
 C_i is the influent TSS concentration (mg/L)
 HLR is the hydraulic loading rate (cm/d)

The third model proposed for wetland sizing is the Kadlec and Knight model (Kadlec and Knight, 1996). This method, like the Reed model, assumes that the wetland acts as a plug flow reactor. Reed *et al.* (1995) and Crites and Tchobanoglous (1998) suggest that the Kadlec and Knight model be employed for phosphorus removal. The Kadlec and Knight model introduces the concept of background nutrient concentrations to account for limiting values. The rate constants that are used in the model are from a large database, which covers many geographical locations and loading rates.

$$\ln\left(\frac{C_e - C^*}{C_i - C^*}\right) = -\frac{K_{A,T}}{q} \quad (2-5)$$

$$q = \frac{365 \times Q}{A} \quad (2-6)$$

Where: C_e is the outlet concentration (mg/L)
 C_i is the effluent concentration (mg/L)
 C^* is the background concentration (mg/L) (table 2.3)
 $K_{A,T}$ is the first order aerial rate constant at temperature T °C (m/yr)
 q is the hydraulic loading rate (m/yr)
 Q is the flow rate through the wetland (m³/d)
 A is the surface area of the wetland (m²)

The aerial rate constant can be adapted for the varying temperatures within the wetland using Equation (2-2) with the values of $k_{v,20}$ and θ listed in Table 2.3.

*Table 2.3 Typical Kadlec and Knight Rate Constants, Background Concentrations, and Temperature Correction Factors for Various Parameters
(Kadlec and Knight, 1996; Wallace, 2003)*

Parameter	Background Concentration C^* (mg/L)	$K_{A,20}$ (m/yr)	θ
BOD ₅	$3.5+0.053 C_i$ ($0 \leq C < 200$ mg/L)	34	1
TSS	$5.1+0.16 C_i$ ($0.1 \leq C < 807$ mg/L)	1000 ^a	1
Organic-N	1.5	17	1.05
NH ₄ -N	0	18	1.04
NO _x -N	0	35	1.09
Total-N	1.5	22	1.05
Total-P	0.02	12	1

^a A rough unsubstantiated estimate; solid settling velocity, w (m/d), is preferred, where $k_{A,T}$ is replace with w .

2.2.7 Agricultural Wastewater Treatment (Case Studies)

There have been many studies performed on wetlands that treat agricultural wastewaters. These studies have been performed in different countries and climates, and all of the studies have resulted in substantial reductions of constituent concentrations. Different types of wetland systems were used in different studies, as well as different types of vegetation, or in some cases, no vegetation.

Drizo *et al.* (2004) monitored a wetland system in Vermont, USA that was treating barnyard runoff and milkhouse washwater. The treatment system consisted of two subsurface wetland cells in parallel following two anaerobic tanks. One of the wetland cells was vegetated with cattails, while the other remained unvegetated. The purpose of the study was to determine the difference in treatment efficiency of vegetated

and unvegetated SSF wetland cells with a 5-day detention time. The study also observed the difference in treatment with and without aeration of the wetland cells. At the end of the study, the BOD₅ removal was determined to be 90% in both the vegetated and unvegetated cells, and the TSS removal was determined to be 97% in the vegetated cell and 87% in the unvegetated cell with aeration. Without aeration, the BOD₅ removal decreased to 50% in the vegetated cell and 58% in the non-vegetated cell, the TSS removal also decreased to 76% in both cells. Ammonia and phosphorous removal was low in both of the cells, but the vegetated cell demonstrated a slight increase in ammonia removal during aeration.

Pries and McGarry (2002) monitored two constructed wetlands treating feedlot storm water runoff from dairy operations in Manitoba, Canada. The first wetland consisted of a single FWS cell with a surface area of 0.5 ha, and a depth of 0.3 m, vegetated with cattails. The second wetland consisted of two FWS cells each with a surface area of 0.5 ha and a depth of 0.3 m, vegetated with cattails. The results from monitoring are presented in Table 2.4. Each of the systems demonstrated good removal of the wastewater constituents, especially nitrogen species and BOD₅. The analysis of this wetland resulted in variations in the wastewater parameter concentrations. In Table 2.4, the BOD₅ and Ammonia in the first wetland and the TSS and TP in the second system demonstrate variability in the influent and effluent concentrations. This was expected and understood in natural systems due to the variable precipitation, which tends to dilute the wastewater, and evapotranspiration, which tends to increase wastewater concentrations.

Table 2.4 Results from Pries and McGarry (2002) Wetland Study

	First Wetland (One FWS Cell)		Second Wetland (Two FWS Cells)	
Nutrient	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)
TSS	70	12	600-20	200-10
BOD ₅	81-5	18-6	124	13
TP	4	3	9-8	9-7.5
Ammonia	25-4	0.2	27	1
TKN	39	6	81	12

Monitoring was performed at a farm in Essex, Ontario Canada (CH2MHill and Payne, 1997), where a wetland was used to treat barnyard runoff and milkhouse washwater. The constructed wetland consisted of a 600 m² serpentine channel that was planted with cattails. The inlet and outlet nutrient concentrations from the study are presented in Table 2.5. This wetland demonstrated an excellent removal of phosphorous and nitrogen species, but there was little reduction in BOD₅ concentration.

Table 2.5 Inlet and Outlet Concentrations Observed at Essex, Ontario Constructed Wetland (CH2M Hill and Payne, 1997)

Nutrient	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)
TSS	119	17
BOD ₅	357	202
TP	25	4
Nitrate	0.2	0.1
TKN	1596	48

Thurston-Enriquez *et al.* (2004) monitored a constructed wetland treating milkhouse washwater and cattle wastewater in Nebraska, USA. The treatment system consisted of a concrete manure storage system with a debris basin, a single FWS wetland cell with a depth of 0.3 m and distribution onto a crop field. The wetland cell was designed to be planted with emergent vegetation after the completion of the study. The inlet and outlet nutrient concentrations from the study are presented in Table 2.6. The

concentrations of all of the constituents demonstrated an increase through the wetland, which implies that there were issues associated with the operation that needed to be addressed. Table 2.6 demonstrates the variability in concentration measurements that was also noted in the study conducted by Pries and McGarry (2002). This variability in wastewater concentrations creates high standard deviations in the data analysis.

Table 2.6 Inlet and Outlet Constituent Concentrations from Thurston-Enriquez et al. (2004)

Constituent	Inlet Concentration Range (mg/L)	Outlet Concentration Range (mg/L)
TP	24-44	21-52
Ammonia	0.1-68	0.2-115
Nitrate	0.1-8	0.2-42
TKN	104-223	145-194

At Oregon State University, a study was performed on a constructed wetland treating the runoff from a feedlot and barn housing 160 cows (CH2M Hill and Payne, 1997). The constructed wetland consisted of six, 6 m wide, 27 m long, 0.3 m deep vegetated FWS wetland cells. The cells were vegetated with a mixture of cattails, bulrushes and grasses. The influent and effluent concentrations from the study are presented in Table 2.7. The results of this study demonstrated a good reduction of all constituents, where TP and ammonia concentration reductions were the least efficient of the entire system.

Table 2.7 Inlet and Outlet Constituent Concentrations from the Oregon State University Study (CH2M Hill and Payne, 1997)

Constituent	Inlet Concentrations (mg/L)	Outlet Concentrations (mg/L)
TSS	542	142
BOD ₅	705	242
TP	33	17
Ammonia	126	65

2.3 CONSTRUCTED WETLANDS IN CANADA

The main challenge to wetland treatment systems in Canada is the cold climate. In Canada, wetlands will freeze during a certain period of the year, whereas in more southern locations, this may not be a limiting consideration. As temperature decreases, the efficiency of the system is also decreases. For instance, at 6°C, the removal of BOD₅ from 240 mg/L to 40mg/L requires a retention time which is double that which would be required for the same conversion at 20 °C (Revitt *et al.*, 2001).

If the water within the wetland were allowed to freeze, then the treatment would stop altogether. For the wetland to remain operational during the colder months, the surface of the wetland can be allowed to freeze. The water level of the wetland can then be lowered such that a dead air space will be achieved between the ice and the water level. Insulation can then be placed around the wetland, which will allow the temperature to remain at an acceptable level for treatment to continue. The presence of an ice cap could lead to the development of anaerobic conditions within the system, which would change the type of treatment being performed. A mechanical aerator can be employed to maintain aerobic conditions within the system. Lower temperatures would also lead to a decrease in the treatment potential of the system, thus, requiring a larger area to continue to provide sufficient wastewater treatment. Sub-surface flow wetlands must be well insulated to maintain the system at the design temperature (Herskowitz, 1986).

This insulation and aeration solution creates a requirement for the monitoring of the wetland through the cold weather in order to maintain optimal conditions. Another option would be to store the water during the non-growing season, and to treat the water when the seasons change. Storing the water reduces the costs of wetland operation since

there is no need for effluent monitoring through the period while the wetland is frozen, and the initial water entering the wetland can be controlled to optimize growth and treatment efficiency. Storage of wastewater requires a basin large enough to accommodate all of the wastewater that will be produced while the system is not functioning, which increases the land requirement, as well as construction costs.

2.4 TRACERS

A tracer is a substance that is present in the water, the pollutant, or can be added to the water to determine flow properties. Many tracers are conservative substances that ease the determination of the properties that govern the water movement. Other tracers are non-conservative substances that have a known decay rate, which can make them as useful as the conservative substances.

2.4.1 Methods of Tracer Studies

The method used to perform a tracer study depends upon the reason for the study. If the purpose of the study is to determine the hydraulic residence time within the system, then a single sampling point can be placed at the outlet of the system to determine the time at which the tracer peak concentration occurs. If the test is employed to determine the flow characteristics, many points need to be placed throughout the system. Both testing methods involve a number of samples being taken at set time intervals. The simplest data collection method employs automatic samplers, which can be set up to collect multiple samples at desired time intervals.

In the case of determining the residence times, the sampling generally starts when the tracer is injected, and continues until a concentration peak is observed, and the tail of

the peak is defined. This method of testing can identify short-circuiting and dead spaces within the system, as well as the actual flow times.

In situations where the test determines the flow properties of the system, samples must be taken at many sampling points, which would require many automatic samplers. This is an expensive endeavor, but enlarging the test area, which implies that the sampling can be done less frequently, can reduce the cost. The number of sample points would then increase, however, sampling less frequently implies that manual sampling could be done, as opposed to using expensive equipment.

There are two main tracer methods for flow determination. The first is to sample at various fixed points within the system, at fixed time intervals (fixed location method). The concentrations that are sampled at each interval are recorded and the size of the plume is interpolated. The second method is to measure the arrival time of the tracer or the evolution of the tracer at fixed reference points (VanderBrought and Vereecken, 2001).

The first method requires a large number of sampling points to adequately determine the dispersion of the tracer. This creates the need for a large area available for testing. If there is no previous dispersion data for the system, then the area of testing must allow for a large amount of dispersion as a safety factor to minimize the portion of the plume that might escape the testing procedure.

The second method requires monitoring of a single plane within the system for the arrival time of the tracer (flux method), where the time and the flux are the important factors. This removes the large area requirement since the monitoring is associated with one plane, and the longitudinal dispersion can be categorized with the flux. The

concentrations are measured at the single plane rather than over an entire system. For this reason, the arrival time analysis of the tracer is considered to be a more efficient method of testing in ground water systems (Vanderbourght and Vereecken, 2001).

Each method of monitoring has its advantages. The sampling of concentrations at defined time intervals is useful for determining flow pathways through a water system that is plagued with obstacles. This method is useful for wetlands that are vegetated with areas of varying density, or soils with boulders or varying components. The flux method is able to provide an overall picture of the movement of the water, however, it will not demonstrate the flow pathways. For this reason the flux method is of no use when determining the physical flow paths of the water.

The fixed location method of transport determination requires more space than the flux method. The fixed location method will demonstrate the flow within the system, while the flux method will give overall flow properties for the system. Each monitoring method is useful for different purposes.

When setting up a tracer study, there are several details of the study that must be taken into account: the method of tracer concentration determination; the amount of tracer; the density of the tracer; and the methodology of the study.

2.4.1.1 *Amount of Tracer*

The amount of tracer that is injected into the system is very important. There must be enough tracer such that the concentration will be detectable at the sample points, and since chemicals are expensive, the smaller the quantity of tracer used, the least costly. There are many different methods used to determine the quantity of tracer to be added.

The two main factors involved in assessing the quantity of tracer to add include: firstly, the detection limit of the testing equipment; and, secondly, the quantity of tracer to be added must be large enough such that if the tracer were to be dissolved evenly throughout the system, the concentration would be above the detection limit.

The background concentrations of the compounds that make up the tracer should be measured throughout the system. This will give a measure of the tracer substance that is already in the system. The amount of tracer that is added to the system should be in large enough quantity such that if the tracer were fully dissolved within the whole system, the concentration would be notably greater (5 times) than that of the background.

Once the detection limits of the equipment and the background concentrations have been established, the amount of tracer that is to be added can be computed. The amount of tracer to be added will be the smallest amount of tracer that will comply with both criteria discussed above.

2.4.1.2 Concentration of Tracer

The proper amount of tracer to add is key for the determination of concentrations during sampling. The density of the tracer is another important consideration and should, ideally, be similar to the density of the wastewater that the tracer is entering. Stream water will have a lower density, while a more concentrated wastewater stream will have a greater density. If the tracer is too dense, then it will sink and will not flow with the water until it has mixed with the water to an equivalent density (Schmid *et al.*, 2004; Chazarence *et al.*, 2003). This would result in erroneous time calculations.

Once the density of the water from the system has been established, the proper concentration of tracer can be determined. Adding the proper amount of tracer to distilled

water will produce the mass of a 1 L sample of water from the system. Computing the mass of tracer that is added will give the maximum concentration of tracer that will have the same density as the water from the system. This maximum concentration will be the concentration used to input the tracer into the system. Some studies have dissolved salt tracers to match the total dissolved solid concentrations of the wastewaters instead of matching the density of the wastewater (Rash and Leih, 1999)

2.4.1.3 Determination of Tracer

The analytical techniques employed to determine the concentration of tracer at sample points are very important. Some of the devices employed for determining concentrations of tracer can be interfered with by other chemicals within the sample. This is most evident in ion selective electrodes, and colourimetric analyses. The voltage reading is based on the ability for the ions to conduct electricity within the solution.

If the technique that is being used is photometric, or colourimetric (opacity or colour based), the clarity of the sample solution is important. A murky sample may result in erroneous readings due to the pre-existing colour or the lack of clarity.

The degree of precision that is required is also important. If the tracer test is being used to determine the flow properties of the system, then high precision (experimental error < 0.1 mg/L) is required to best determine the components of flow. If the study is used to determine the residence time in a system, then the precision requirements may be lowered. With lower precision, concentration peaks are still visible, but the concentration at the peaks need not be exact.

2.4.2 Dye and Chemical Tracers

There are a number of different types of tracers that could be used in studies. The information that is required from each test, as well as the starting point, are the factors of the greatest importance. There are many lesser factors that are also involved in tracer selection.

The simplest of all tracers is the dye tracer. As its name suggests, the dye tracer is a coloured dye that is injected into the water and the concentration of the dye is measured as an intensity of colour at sampling points. The dyes can also be used to determine the interaction between the soil and the water. Chemical tracers such as bromide and sodium chloride can be used in the same manner as dye tracers and, therefore, they have been included in this section.

The dye tracer is best suited for surface waters. The larger the water system, the more dye will be required. Tests have been conducted on streams with dyes, but their use for rivers requires more dye and better evaluation techniques due to the large cross sections and greater mixing in a river.

Flowing surface water, interacts with the soil matrix along the banks and beds in a process called hyporheic exchange. Since dye tracers mix with the water and react to the environment in the same manner as water, they are very useful in the determination of the effects of hyporheic exchange within streams (Laenen and Bencala, 2001). This exchange results in an increased residence time of the dye within the stream. Thus, the determination of transport within the system has an added retardation factor (Lin *et al.*, 2003).

Some of the dye tracers, such as Rhodamine WT, react with light and degrade in a process called photodegradation (Leanen and Bencala, 2001). This has advantages and disadvantages. A dye tracer that remains in the water system will degrade with time with light and will have less chance of causing alarm when found in the discharge water system since there will be no colour remaining in the water. The rate of photodegradation can be estimated with respect to the given environmental conditions during the testing period, and this degradation is then added to the equation for transport within the stream.

2.4.3 Uses of Tracers

Tracers can be used to determine characteristics of water through any flow situation. The flows in environmental systems that are most frequently monitored with tracer studies are surface and ground water flow. Both types of flows are governed by the same principles. In simplest terms, the water will flow from the higher energy areas to the lower energy areas. The distribution of the solids (tracers, contaminants, etc...) is also governed by the same basic concepts.

With any flow of water where there is turbulence, the distribution and spreading of a tracer plume is governed by three basic concepts: advection, diffusion and dispersion (Bedient *et al.*, 1994). The magnitude of the effect of these three factors depends upon the method of tracer input. The amount of time required for tracer injection, the geometry of the tracer injection (point source, line source) and the position of the tracer injection are all important elements that require consideration.

2.4.3.1 *Flow Within Free Water Surface Wetlands*

The primary distribution of the tracer within the open channel is generally via advection. Advection is the movement of the tracer along with the bulk flow of the wastewater. Therefore, if the movement of the tracer were based solely on advection, the equation for the motion of the tracer would be that of the movement of the water. This situation is not realistic as there are more stresses placed upon the system that influence the flow. The dispersion within the system, and any mixing from the movement of plant stalks must also be taken into consideration. There are some tracers that are non-conservative. The decay of these tracers can be accounted for with the addition of a decay term.

The next important factor in the tracer study is the type of injection. If the injection is an instantaneous injection, the distribution will be different than if the injection were constant.

Along with the determination of flow, tracers have other uses within a water system. In the instance of wetlands or other treatment systems, a tracer can help to determine the efficiency of the system. The tracer can be used to demonstrate any dead zones, which result in a shorter retention time calculation than expected, or areas in the system where the tracer collects, which result in a longer detention time than expected. The tracer can also be used to determine if there is any short-circuiting. If this were the case, the tracer would appear in sections earlier than anticipated.

2.4.4 Previous Studies

There have been many studies performed with tracers. Some of the studies that were reviewed have dealt with dye tracers, and others with salt tracers. The studies had different purposes and were performed on different types of systems.

Kadlec (1994) used a lithium chloride tracer to determine the best type of model to use to describe flow in a wetland. Three models were analyzed: plug flow with dispersion, continuously mixed reactor, and a network model, which is a model that separates the wetland into finite sectors and monitors the effect of flow from each sector on the other sectors. Analysis of the effluent plume resulted in no clear advantage of any of these models. Therefore 26 points in the wetland were analyzed for tracer concentrations. The analysis of the interior points demonstrated that the network model best described the wetland of study.

Schmid *et al.* (2004) studied density stratification of salt tracers in a laboratory wetland simulation. They determined that the initial density of the salt tracer was important in deeper wetland systems, due to a retardation in tracer flow as the bulk of tracer sank before adequate mixing occurred, but in shallow systems (> 0.4 m) the retardation effect was minimized.

Bowmer (1987) and Lin *et al.* (2003) monitored the flow of Rhodamine WT, a dye tracer, in conjunction with a bromide tracer to determine the usefulness of Rhodamine WT as a tracer in wetlands. Both studies determined that the Rhodamine WT is acceptable in low hydraulic retention time systems (< 5 days). Lin *et al.* (2003) also examined the sorption rate, photodegradation rate, and desorption rate of the Rhodamine

WT to better explain the results of the studies which yielded 85% capture of bromide tracer, but only 59% capture of Rhodamine WT.

Simi and Mitchell (1999) used Rhodamine WT as a tracer to characterize the dead zones within a constructed wetland. Tracer tests were performed on two cells of the wetland, resulting in a capture of 82% and 79% of the original tracer mass. After analysis of the retention time of the tracers, it was determined that the volume of the wetland that the tracer flow occupied was 2800 m³, while the design volume was 3900 m³, therefore 30% of the wetland cell was concluded to be a dead zone.

CHAPTER 3

METHODOLOGY

3.1 SITE DESCRIPTION

The constructed wetland used in this study was constructed on the Dignard dairy farm in 1994 and was designed to treat the wastewater from a herd of 150 livestock units. The dairy operation produces three types of wastewaters: washwater from the cleaning of milkhouse equipment, stormwater runoff from the cattle exercise yard and liquid runoff from the solid manure pile. Prior to the construction of the wetland, the liquid manure runoff and the milkhouse washwater were stored in a lagoon and periodically spread onto cropland, while the runoff from the exercise yard was not collected. The farmer was in search of a method or technology of treating the liquid wastewater which did not require application on to cropland. A schematic of the wetland is presented in Figure 3.1. Aerial photographs of the wetland system from 1996 and 2003 can be found in Appendix A.

Since the start of operation in 1996, the wetland has been fed by three different sources: stormwater runoff from an exercise yard, milkhouse washwater and runoff from a solid manure pile. The solid manure is stacked on a concrete slab with the use of an air piston. Runoff from the slab is collected in an anaerobic lagoon where it is mixed with the washwater from the milkhouse. The effluent from the lagoon is pumped at a rate of $11\text{ m}^3/\text{day}$ to a facultative pond. In the facultative pond, the lagoon effluent is mixed with the stormwater runoff from the exercise yard.

Figure 3.1 Dignard Constructed Wetland System

Throughout the two-year study, between May and November, the effluent from the facultative pond was pumped at a rate of $21.9 \text{ m}^3/\text{day}$ to the first vegetated wetland cell (FWS #1: 41m length, 33m width and 0.3m depth), using a four inch perforated PVC header pipe. The cell was densely vegetated with *Typha latifolia* (common cattails), and was designed to have a detention time of 20 days. The depth of the wetland cell was controlled by a v-notch weir at the outlet. Sampling units were placed within the cell at nine different points to draw samples from the water column and the sediment zones, as illustrated in Figure 3.2. Sample points were selected such that the sample locations followed the anticipated main flow path of the system. The location of point 9 was used to assess if any of the flow would reach that particular area of the cell.

The sampling apparatus consisted of 0.48cm inside diameter Tygon tubing to draw the water column samples. The inlet of each of the sample tubes was incased in a 20 L sieve, with 0.64 cm perforations. The sieve was installed to protect the sample tubes

from being clogged with large fractions of plant matter present in the wastewater. Each of the sample points that removed pore water samples from the sediments were equipped with a porous ceramic cup system with a 300ml sample storage volume to remove liquid samples without disturbing the sediment zones. Images of the sampling apparatus as well as the protective sieve, installed, in the wetland can be found in Appendix A.

Figure 3.2 Sampling Locations in First Vegetated Wetland Cell (FWS #1)

From FWS #1, the wastewater flowed to the aerobic pond (Pond cell: 66m length, 33m width and 0.7 m depth). Vegetation was absent in Pond cell, which was designed to have a detention time of 88 days. Sampling apparatus were placed at nine different points within the cell to sample from the water column (I-IX) and at six points in the sediment zone (I-III, VII-IX), as illustrated in Figure 3.3. The locations of the sampling points within the pond cell were selected to be evenly spaced along three planes within the cell.

Figure 3.3 Sampling locations in Anoxic Pond Cell (Pond cell)

From Pond cell, the wastewater entered another densely vegetated cell (FWS #2: 33m length, 33m width and 0.3 m depth). The vegetation in the cell was mainly comprised of *Typha latifolia* (common cattails). The height of wastewater in the cell was controlled by a v-notch weir at the outlet. Sampling apparatus were placed at eight points within the cell to draw samples from the water column and the sediment zones, as illustrated in Figure 3.4. The sample point locations in FWS #2 were selected in the same manner as for FWS #1. Point i was selected to assess if any of the flow would reach that area of the cell.

Figure 3.4 Sampling Locations in Second Vegetated Wetland Cell (FWS #2)

3.2 SAMPLING PROTOCOL

During the first year of the study, the wetland was sampled based on a bi-weekly schedule starting May 21, 2003 and ending November 4, 2003. During the second year of the study, the wetland was also sampled based on a bi-weekly schedule, starting May 25, 2004 and ending August 4, 2004. The samples were collected on the Tuesday of each of the designated sampling weeks. In the event of rainfall, the sampling was delayed until twenty-four hours after the peak precipitation of the rainfall event.

During a sampling event, grab samples from the water column were taken at the influent and effluent of each wetland cell. At the sampling points within each wetland cell, grab samples were taken from the water column (2003 and 2004) and the pore water within the sediments (2003).

At every sampling point, two 300 ml samples were drawn from the system. The in-situ analyses (temperature, DO, pH) were performed from one of the samples, which was then stored in a cooler with icepacks unpreserved and transported for laboratory analysis of BOD₅ and TSS concentrations. The other sample was acidified to a pH of 3

with concentrated sulfuric acid, stored in a cooler with icepacks and transported for laboratory analysis of ammonia, nitrate, TKN and TP concentrations.

3.2.1 Inlet and Outlet Samples

Two grab samples were taken from each of the wetland cells. Samples were obtained using a sampling vial on an extendable pole. Samples were then analyzed for temperature, pH and DO, then stored in a cooler with icepacks, preserved when required and transported for laboratory analysis of BOD₅, TSS, TP, ammonia, nitrate and TKN concentrations.

3.2.2 Water Column Samples

Water column samples from within the cells of the wetland were drawn through the 0.48 cm Tygon tubes using a peristaltic pump. Samples were then analyzed for temperature, pH and DO, then stored in a cooler with icepacks, preserved when required and transported for laboratory analysis of BOD₅, TSS, TP, ammonia, nitrate and TKN concentrations.

3.2.3 Sediment Samples

Sampling of the sediment pore waters needed to be conducted in such a way that the sediments remained as undisturbed as possible. The apparatus used for the sampling were not to alter the flow dynamics of the system, nor the processes at work within the sediments. Thus, placing a gravel sampling zone in the sediment, for example, would have created an area within the sediments with a high permeability which would have influenced the flow, as well as introduce a medium for new bacterial growth, thereby affecting the treatment processes within the system.

For this reason, sediment zone samples were drawn with the use of porous cups. The cups were placed in the sediments at each of the sample locations. The porous cups allowed fluid to pass through their pores due to a pressure differential between the two sides of the porous surface (0.8 bars). This pressure was induced on the cups, by a hand vacuum pump, the day before the sampling was scheduled to take place, which allowed the apparatus to fill with a sample such that collection could be done quickly on the sampling day.

The porous cups that were used to collect samples acted as large filters, which implied that the sediments did not get disturbed nor removed during sampling. The liquid sample that was taken from the cups had a large fraction of the organic portion filtered out, therefore analyses for TSS and BOD₅ were not performed. Only one 300 ml sample was taken from the cups. These samples were analyzed for temperature, pH, and DO concentrations. The samples were then stored in a cooler with icepacks, preserved with concentrated sulfuric acid and transported for laboratory analysis of ammonia, nitrate, TKN, and TP concentrations.

3.3 TRACER STUDY

A bromide tracer study was conducted on each of the two vegetated cells of the wetland (cells 1 and 3). This study was used to establish the distribution of wastewater flow through the wetland cells. The tracer was introduced into each cell at the same location as the expected wastewater input. During the first year of operation (2003), the inlet to FWS #1 was a point source, due to a clogged inlet header. This allowed for the comparison of point source inlet and sheet flow inlet conditions, which was re-established during the second year of the study (2004).

During the first year of the study (2003), the two cells were dosed with 750-800L of bromide tracer solution consisting of wastewater drawn from the pond cell and mixed with sodium bromide in a 1000 liter tank. The concentration of bromide in the tracer solution was approximately 5000 mg/L. A second tracer test was conducted in the first wetland cell in the middle of the second sampling year (2004), which allowed for the comparison of the two flow dynamics consisting of a point inlet and header inlet. For the second test, the cell was dosed with 1000L of bromide tracer solution with a concentration of 6000 mg/L. The concentration of tracer was increased during the second year to achieve a faster sample analysis due to the higher bromide concentrations.

A daily composite sample was drawn at each of the sampling points of the cells. A peristaltic pump collected 30ml from each sampling point every 30 minutes (controlled by a Chronotrol XT digital timer) for the duration of each test (19-26 days). These samples were analyzed for bromide concentration with the use of a model 96-35 Orion bromide electrode, to determine the tracer movement within each of the cells.

3.4 ANALYTICAL PROCEDURES

3.4.1 *Total Suspended Solids (TSS)*

The total suspended solids were analyzed in the laboratory using standard method 2540 D. "Total Suspended Solids Dried at 103-105°C" (APHA, 1998). Samples were stored, unpreserved at $4 \pm 1^\circ\text{C}$. The analysis was conducted within 48 hours of collection of sample.

3.4.2 Total Phosphorous (TP)

The total phosphorous concentrations of the samples were analyzed in the laboratory using standard method 4500-P (APHA, 1998). The “persulfate digestion method” was used to digest the form of phosphorous within each of the samples to ortho-phosphates, which were then analyzed using the “Ascorbic Acid Method”. Samples were stored, preserved with sulfuric acid to a pH of <3, at 4±1°C. The analysis was performed within 28 days of sample collection.

3.4.3 Ammonia

The ammonia concentrations of the samples were analyzed in the laboratory using standard method 4500-NH₃ D “Ammonia-Selective Electrode Method” (APHA, 1998), with a model 95-12 Orion ammonia electrode. Samples were stored, preserved with sulfuric acid to a pH of <3, at 4±1°C. Analysis was done within 28 days of collection of sample.

3.4.4 Nitrates

The nitrate concentrations of the samples were analyzed in the laboratory using standard method 4500-NO₃⁻ D. “Nitrate Electrode Method” (APHA, 1998), and a model 9307 Orion nitrate electrode. Samples were stored, preserved with sulfuric acid to a pH of <3, at 4±1°C. The analysis was conducted within 28 days of sample collection.

3.4.5 Total Kjeldahl Nitrogen (TKN)

The TKN concentrations of the samples were analyzed in the laboratory using standard method 4500-N_{org} B. “Macro-Kjeldahl Method” (APHA, 1998). Samples were stored, preserved with sulfuric acid to a pH of <3, at 4±1°C. The analysis was performed within 28 days of sample collection.

3.4.6 Biological Oxygen Demand (BOD₅)

The BOD₅ concentrations of the samples were analyzed in the laboratory using standard method 5210 B. “5-Day BOD Test” (APHA, 1998), and a model 97-08 Orion oxygen electrode. The analysis was conducted with three different dilutions of each sample. Samples were stored, unpreserved at $4\pm 1^{\circ}\text{C}$. The analysis was initiated within 48 hours of collection of sample.

3.4.7 Bromide

The bromide concentration of each of the samples was analyzed in the laboratory with the use of a model 96-35 Orion bromide electrode. To overcome the interference from the ionic species within the samples, the concentration of bromide within each sample was increased by 20ppm by adding 1ml of 1000ppm bromide solution to 50 ml of sample. The addition of a known amount of bromide to the samples ensured that the ratio of bromide concentration to all of the interfering ion concentrations was higher than required for the probe to accurately determine bromide concentration. Samples were stored, unpreserved, at room temperature and were analyzed within 5 days of collection of sample.

3.5 SEDIMENT MAPPING AND VEGETATION DENSITY MEASUREMENT

At the beginning of the second year of study, the sediment height and vegetation density were measured in FWS #1. The cell was separated into a grid with sections 1.25m wide and 2.15m wide. The height of sediments was measured using a meter stick at the center of each of the grid sections. The vegetation density was measured as the fraction of the grid section, out of 10, that contained plant stalks.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 TRACER STUDIES

4.1.1 Overview

For both of the vegetated cells, the inlet was designed to be a header (line source) along the length of the inlet plane, while the outlet was a point along the southern side of the effluent plane (Appendix A). A conceptual analysis of the flow (a hypothesis based on the inlet and outlet positioning) that would be expected within each of the cells, neglecting plant media, would indicate that the stream should generally flow directly from the inlet to the outlet (Figure 4.1). This would imply that the flow would only pass through half of the entire area of the cell. Dispersion and mixing would allow the flow pattern to expand slightly towards the no flow zones, but there would always be areas of the cell that would not be contacted by the flow, and hence the wastewater.

Figure 4.1 Simplified Hydrologic Analysis of Expected Wetland Flow Patterns

Changing the outlet from a point along one of the sides to a series of weirs along the outlet end of the cell would create a sheet flow dynamic over the entire cell. This would better distribute flow and would eliminate some of the dead zones within the cell. The elimination of these dead zones would mean that preferential flow pathways within the cell would become the primary inhibitor to the sheet flow dynamic that is ideal in wetland design.

The inlet flow that was observed in FWS #1 differed from what was expected in the first year. This was due to the inlet header developing clogs, which resulted in the influent pipe being removed from the distribution header and placed along the north bank of the cell. The differences in inlet and outlet dynamics in FWS #1 during the 2003 season are representative of a point source inlet with a point source outlet. The hydrologic analysis of the flow in FWS #1 (Figure 4.1) would suggest that the flow would be concentrated in a direct path from the inlet to the outlet, but dispersion and mixing would draw the flow out transversely. The dispersion would not be sufficient to reach all of the areas of the cell, thus, the development of dead zones would be expected.

The simplified hydrologic assumption of flow pathways was consistent with the general constituent concentration distributions observed within the cells, as well as the sediment distribution. The validity of these assumptions was assessed with the use of a tracer study. The difference in flow dynamics in FWS #1 between the two sampling seasons provided an opportunity to observe different dispersion patterns for the tracer, and hence the wastewater, throughout the cell. The raw data from the tracer studies can be found in Appendix C.

4.1.2 Tracer Distribution

During each of the tracer studies, daily composite samples were drawn from each of the points within the wetland cell that was being analyzed. Outlet tracer concentrations from each of the cells are presented in Figure 4.2. The figure demonstrates the normalized concentrations (C/C_o) of each of the three tracer studies. The hydraulic retention time of each cell was determined from the time required for the outlet tracer concentration to reach a maximum value. The retention times were determined to be 14 days for FWS #1 in 2003 (85% recovery of tracer), 13 days for FWS #1 in 2004 (96% recovery of tracer) and 11 days for FWS #2 in 2003 (79% recovery of tracer).

Figure 4.2 C/C_o Curves for the Three Tracer Tests

The general shape of each of the curves would indicate that flow within the cells could be best generalized as approaching a completely mixed flow condition. The curves for the two studies performed on FWS #1 were found to have multiple local maxima and minima, which would not be expected in a completely mixed system. These maxima and

minima would suggest that there were multiple flow pathways channeling the flow through the cell. Different retention times would be expected for each of the flow pathways and the superposition of these distinct flow paths resulted in the multiple peaks observed in Figure 4.2.

4.1.2.1 *First Vegetated Cell (FWS #1)*

As previously mentioned, at the beginning of the first year of study, the inlet of the wetland was re-located from the header to a point along the northern bank due to a broken header pipe. The resulting area of flow was reduced from the expected design area. With the tracer concentrations measured from the daily composite samples, the area of flow was estimated, by krigging with the measured maximum tracer concentrations determined at each sample point, as shown in Figure 4.3. The darkest portion of the figure shows the main area of flow (>60% of tracer mass), while the middle area indicates locations where 40-60% of the tracer flow occurred, lighter area accounts for dispersion of the tracer (20-40% of tracer flow). The zones where the tracer did not reach are visible from the figure, as well. As can be seen, there was limited mixing upstream of the inlet. The actual flow pattern in this cell was relatively similar to the patterns hypothesized in figure 4.1.

Figure 4.3 Tracer Distribution in FWS #1 During the First Year of Study (2003)

Taking into account the residence time of the tracer ($T = 14$ days) and the average flow rate through the wetland ($Q_{avg} = 20.9 \text{ m}^3/\text{day}$), which was calculated by averaging the pumped inlet flow rate ($21.9 \text{ m}^3/\text{day}$) and the outlet flow rate computed from the water balance presented in Appendix B ($20.06 \text{ m}^3/\text{day}$), and using Equation 4-1, the cell volume receiving the flow was determined to be 306 m^3 , and the surface area of the flow (given a design depth of 0.3 m) was calculated to be 1020 m^2 . The use of the design depth neglects any effect on the flow volume from the accumulation of sediments; this is a simplifying assumption since there was no analysis of the flow properties within the sediments performed on the wetland cell. From the tracer calculations, it would appear that 75% of the wetland volume was being used for treatment in the first year of the study (2003). However, the tracer distribution (Figure 4.3) did not support that this was actually the case. This was attributed to a lower than expected flow rate ($< 20.9 \text{ m}^3/\text{day}$) during the tracer study, which could be the result of a damaged pump; or, since the pump was not

controlled by the same timer as the sampling mechanisms, the operation of the pump may have stopped while the tracer study was still underway.

$$Q_{avg} \times T = V \quad (4-1)$$

$$20.9 \text{ m}^3/\text{day} \times 14 \text{ day} = 306 \text{ m}^3$$

During the second year of study (2004), the inlet was returned to a header configuration. This allowed for a second tracer study to monitor the differences in flow patterns between the two different inlet regimes. During the second year of the study (2004), the dosing of the wetland was controlled by the same timer that controlled the samplers. This ensured that the wetland was being dosed at a controlled rate.

The tracer distribution (Figure 4.4) of the second year (2004) demonstrated that the header was also not dosing the entire length of the wetland, indicating potential issues with the inlet header configuration. Another unexpected observation was that point 4 demonstrated a small capture (30%) of the tracer, while 1 and 6 demonstrated a large capture of tracer. This would suggest that point 4 was in a low flow area, either blocked by sediment piles or extremely dense vegetation, and the tracer passed around the sampling point. Unfortunately, without a second sampling point between point 4 and the southern bank of the cell an absolute answer could not be formulated from the results. The pattern of flow distribution is similar to that which was discussed in Section 4.1.

Using the residence time determined by the tracer study (13 days), and the average flow rate through the cell (20.9 m³/day), the volume of the cell employed under the new inlet flow regime was computed from the flow of tracer (using Equation 4-1) as 272 m³, which corresponds to 67% of the total volume of the cell. The retention time of the tracer in FWS #1 was determined to be fairly similar in both years of the study, however the inlet pump was controlled in the second year of the study, thus, the retention

time obtained in 2004 was most likely more accurate than the retention time obtained in 2003.

Figure 4.4 Tracer Distribution in FWS #1 During the Second Year of Study (2004)

From the tracer study, the distribution of the tracer (Figure 4.4) demonstrated that the tracer contacted more than the 67% of the wetland surface area determined from the retention time calculations. The main flow path of the tracer covered most of the 67% of the area, while the dispersion of the tracer accounted for the increase in treatment area beyond the 67% that was computed. These calculations provided an estimate of the total treatment area. It would also be expected that the areas of treatment that received the lower concentrations of the tracer (from dispersion) would also generally receive lower concentrations of the wastewater constituents.

4.1.2.2 *Second Vegetated Cell (FWS #2)*

The tracer study was carried out on the third cell of the wetland in the first year of the study (2003). A second study had been planned for the second year, to verify that the flow through the cell did not change, however, the equipment failed as the test started, and time constraints did not allow for the test to be re-started. The inlet and outlet dynamics (header inlet and point outlet) of the cell were the identical for the two years, and it was surmised that the flow patterns would not have changed significantly. Similarities in the nutrient concentration distributions throughout the cell (Section 4.2) also supported the assumption that the flow through the cell was similar during both years of study. The tracer distribution was similar to what is hypothesized in figure 4.1.

The tracer retention time in the cell was determined to be 11 days. From the retention time of the tracer within the cell, the volume of the cell that the tracer contacted was computed (using equation 4-1) to be 424 m^3 (75% of design cell volume). The tracer distribution demonstrated that the main flow of the tracer was directly towards the outlet, with slight dispersion towards no flow portions of the cell (Figure 4.5).

Figure 4.5 Tracer Distribution in FWS #2 During the First year of Study (2003)

Monitoring of the tracer concentration profiles within the wetland indicated that there were preferential flow pathways throughout the two vegetated cells. There were sampling points within the wetland cells where lower concentrations were recorded, but these points were in locations that would indicate there was minimal flow to these points (Figure 4.1). This would have likely been the cause of the low concentrations, rather than high treatment efficiency.

4.2 REMOVAL OF CONSTITUENTS

The design of a wetland treatment system depends upon the strength of the wastewater stream that is to be treated. The higher the constituent concentrations within the wastewater stream, the larger the wetland area required to remove the constituents from the wastewater. To maintain the wetland design area as small as possible, the wastewater should receive treatment before it enters the first marsh cell of the wetland. The marsh-pond-marsh cells that comprise the actual wetland serve mainly as a polishing

stage. There are many methods of removing constituents from the wastewater before it enters a wetland system. In this study, the wastewater is treated in an anaerobic lagoon, and then in a facultative pond before it enters the first wetland cell.

Figures illustrating the layout of the wetland along with the inlet and sampling locations can be found in Appendix A. The raw wastewater constituent concentration data from the two years of wetland monitoring can be found in Appendix B.

Constructed wetlands, being “natural” treatment systems that are exposed to environmental stresses daily result in variable data throughout the operating season. The annual patterns of concentrations are discussed in Section 3.1.1, and are demonstrated in the concentration values at other wetlands as well (Pries and McGarry, 2002; Thurston-Enriquez *et al.*, 2004), which were presented in Section 2.2.7.

4.2.1 Removal in the Lagoon and Facultative Pond

At the Dignard constructed wetland, the lagoon is located at the base of the solid manure pile and collects the milkhouse washwater, as well as the runoff from the solid manure pile. Wastewater that is collected in this lagoon contains a high concentration of wastewater constituents. Since there is no dissolved oxygen in the lagoon wastewaters, anaerobic bacteria thrive. Anaerobic treatment of wastewater is an efficient method of quickly reducing the organic loads in wastewaters with high concentrations. The large surface area of the lagoon and the low velocity allow for the settling of solids from the wastewater. The settling of solids removes a portion of the organic matter, as well as phosphorous in the wastewater. The depth of the lagoon allows for anaerobic activity which further decreases organic matter as well as provides organic nitrogen and nitrate reduction. The pH of the wastewater in the lagoon (7.8 ± 0.6 in 2003 and 7.5 ± 0.3 in 2004)

allows for volatilization of ammonia (Ferguson *et al.*, 1984). If the nutrient concentrations within the lagoon were to decrease sufficiently, wind aeration could return the upper depths of the lagoon to an aerobic state, which would decrease the treatment efficiency of the lagoon with respect to the removal of organics.

To avoid aerobic conditions in the lagoon, the wastewater is pumped to a facultative pond. The lower nutrient loading of the pond allows wind aeration over the surface of the pond to keep the top portion of the pond under aerobic conditions while the deeper regions are anaerobic. This treatment is less effective in terms of removal of organic matter than the treatment in the lagoon, but the aerobic and anaerobic conditions of the pond are conducive to the removal of nitrogen in the wastewater.

Figures 4.6-4.11 show the average concentrations of nutrients entering the lagoon and the facultative pond and the removal efficiency of each wetland component. During 2003 and 2004, the lagoon demonstrated a large reduction (>75%) of all of the nutrients that were monitored.

Evaluation of the effectiveness of the facultative pond was difficult due to unexpected circumstances. During the first year of the study, the sampling of the “FWS #1 influent” (also the effluent from the facultative pond) from the wetland was not obtained from the point at which the wastewater entered the wetland. The wetland operator had moved the influent pipe from the inlet header because the header was not functioning properly. The inlet to the wetland was changed from a line input to a point input further down the side of the wetland cell (Appendix A). The resulting “inlet” samples were collected upstream of the actual inlet, in a stagnant area of the wetland cell. Therefore lower concentrations than the actual influent concentrations were measured.

Without samples of the influent wastewater constituent concentrations, there can be no analysis of the facultative pond's treatment efficiency, or of the efficiency of the first wetland cell. In an attempt to remedy this discrepancy, an inlet concentration was estimated using the Kadlec and Knight (1996) model (Equation 2-5) and the constituent concentration data collected at sample point 5 as shown in Figure 3.2. The tracer study employed to analyze the flow in FWS #1 during the first year of study was used to estimate the retention time to point 5 of FWS #1, which was 5 days. Using Equation 2-5, the retention time at point 5 and the inlet flow from the pump ($20.9\text{m}^3/\text{day}$), the FWS #1 influent concentrations were computed. For all of the wastewater constituents, the estimated FWS #1 influent concentrations resulted in higher values than the facultative pond concentrations, signifying that some of the assumed model parameters were likely not applicable to this particular wetland, but without any further information, they were the best values available. Before the sampling began during the second year of the study, the header was repaired and the sampling proceeded as originally planned.

The TSS concentrations (Figure 4.6) show a similar trend in the removal of solids within the lagoon in both years of the study. Due to the assumptions made in the Kadlec and Knight model regarding the efficiency of settling, the assumed FWS #1 influent TSS concentrations were too elevated ($\sim 10^{22}$) to be representative and, and they were, therefore, not presented with the data.

Figure 4.6 TSS Concentrations in Lagoon, Facultative Pond and FWS #1 Influent in both years of Study

The TP concentrations (Figure 4.7) demonstrated a reduction in concentration trend in the lagoon, but did not change significantly in the facultative pond. The removal of TP in both of these stages of treatment was associated with sedimentation (Kadlec and Knight, 1996). During both years of the study, the TP concentration decreased in the lagoon, but not in the facultative pond, as was the case with the TSS concentrations, which tended to agree with arguments presented by Kadlec and Knight (1996).

Figure 4.7 TP Concentrations in Lagoon, Facultative Pond and FWS #1 Influent in *both years of Study*

The ammonia concentration (Figure 4.8) demonstrated a concentration reduction trend within the lagoon, but there was no significant decrease in the concentrations in the facultative pond. The two primary methods for the reduction of ammonia concentration in wastewater are the oxidation to nitrate, which is a result of strict aerobic bacterial activity, and volatilization at pH greater than 7.5. The lagoon was anaerobic, thus, oxidation of ammonia did not occur, however, the pH was in the range required for volatilization. In the facultative pond, the pH was also within an acceptable range for volatilization (8.3 ± 0.4 in 2003 and 8.2 ± 0.3 in 2004), but the concentrations did not indicate a reduction in concentration. This indicated that organic nitrogen was being reduced to ammonia at the same rate as the ammonia was volatilized.

Figure 4.8 Ammonia Concentrations in Lagoon, Facultative Pond and FWS #1 Influent in both years of Study

The nitrate concentrations (Figure 4.9) demonstrated a reduction in concentration trend in the lagoon, but not in the facultative pond. The low nitrate concentrations were removed quickly in the lagoon. During the first year, the estimated FWS #1 influent concentrations were higher than the facultative pond concentrations, but the concentrations from the second year indicated that there was little change in the nitrate concentration in the facultative pond, which would suggest that the computed concentration values overestimated the actual influent concentrations. The nitrate concentrations in the wastewater are already at background levels, and there is little to no change throughout the system. The assumption made within the design model is that there is a high influent nitrate concentration in the wastewater, and the wetland treatment will reduce that concentration, where as in this particular system, there is not an elevated nitrate concentration to begin with.

Figure 4.9 Nitrate Concentrations in Lagoon, Facultative Pond and FWS #1 Influent in both years of Study

The TKN concentrations (Figure 4.10) also exhibited a reduction in concentration in the lagoon, but no difference was observed in the facultative pond. Without TKN analysis from the second year of study, there can be no assumptions made regarding the validity of the estimated FWS #1 influent concentrations.

Figure 4.10 TKN Concentrations in Lagoon, Facultative Pond and FWS #1 Influent in both years of Study

The BOD₅ concentrations (Figure 4.11) showed a reduction in concentration in the lagoon as well, but no significant change in the facultative pond. The greater reduction of organics in the lagoon was expected based on the higher amount of anaerobic bacterial activity. The facultative pond was used by waterfowl as a resting place, therefore the waste from these birds increased the organic concentrations in the system, as did the significant amount of algae that was found in the pond.

Figure 4.11 BOD₅ Concentrations in Lagoon, Facultative Pond and FWS #1 Influent in both years of Study

Lagoons and facultative ponds are efficient for the primary treatment of agricultural wastewater due to the long retention time associated with these units, which allows for the storage and treatment of wastewater. Wetlands offer the polishing of primary treatment effluent which is relatively rapid due to the large areas available for bacterial growth, as well as the availability of oxygen and the flora and fauna growing within the cells.

4.2.2 Overall Removal within Wetland System

The concentrations measured at each of the sites demonstrated the variability that was discussed in the above sections and is supported by the literature (Pries and McGarry, 2002; Thurston-Enriquez *et al.*, 2004). Trends in average concentration distributions were verified with the use of ANOVA. Where these trends are significant with respect to ANOVA, the values of f and f_{crit} are presented. Where f and f_{crit} are not presented, the trend that is being discussed is the average concentration, but the

variability of the data is not accounted for. The trend in variability of the concentrations is similar at all of the sampling points, therefore the change in average concentrations can be expected to be representative of what is actually happening in the wetland without accounting for the 95% confidence intervals (which are large due to the variability)

During the first year of the study (Table 4.1), wastewater constituent concentrations were extremely variable. This would be expected in constructed wetlands due to the environmental stresses placed on the systems. Rainfall events increase the flow through the cells and reduce the constituent concentrations by dilution, however, in the warmer summer season; the evapotranspiration of water from the system concentrates the wastewater and reduces the flow.

Table 4.1 Wastewater Constituent Concentrations ($\pm$ 95% CI) in each Wetland Cell (2003)

Constituent	FWS #1 influent	Pond influent	FWS #2 influent	FWS #2 effluent
TSS	463.18 ($\pm$ 233.43)	205.11 ($\pm$ 98.51)	129.25 ($\pm$ 28.04)	80.29 ($\pm$ 51.21)
TP	19.47 ($\pm$ 6.46)	20.97 ($\pm$ 6.05)	15.97 ($\pm$ 3.45)	13.01 ($\pm$ 3.49)
Ammonia	106.75 ($\pm$ 32.03)	13.58 ($\pm$ 6.89)	13.59 ($\pm$ 7.25)	5.28 ($\pm$ 3.27)
Nitrate	11.01 ($\pm$ 4.06)	1.36 ($\pm$ 0.36)	0.89 ($\pm$ 0.32)	1.00 ($\pm$ 0.55)
TKN	145.05 ($\pm$ 46.16)	39.29 ($\pm$ 7.55)	30.27 ($\pm$ 8.93)	24.3 ($\pm$ 7.06)
BOD ₅	341.23 ($\pm$ 181.19)	79.44 ($\pm$ 21.73)	64.57 ($\pm$ 2.58)	50.99 ($\pm$ 11.52)

The TSS concentrations were too variable at each of the sampling locations to make any general statements regarding the observations with respect to the removal of solids. The TP concentrations did not demonstrate any significant difference between any of the wetland cells, indicating that the reduction of TP had more than likely reached a

steady state. Reduction of TP concentrations is achieved primarily by sorption onto sites within the sediment layers, but plant uptake does account for some removal as well (Kadlec and Knight, 1996). The plants use the phosphorous as a nutrient for growth, and as the plants die and decay, they release the phosphorous back into the wetland system. A reduction in TP concentration would typically signify that the rate of sorption and uptake of phosphorous is greater than the rate of release of phosphorous from decaying plants.

The concentration of ammonia demonstrated a significant reduction in the first cell of the wetland, but no significant change in the remainder of the cells. The pH measured in all of the wetland cells was between 7.3 and 7.5, therefore, little volatilization of ammonia was expected. Figure 4.7 (Section 4.2.1) demonstrated that the assumption used to estimate the FWS #1 influent concentrations in 2003 did not correlate well with the trends observed in 2004 with respect to ammonia concentrations for the FWS #1 influent. The estimated concentrations for the FWS #1 influent were higher than those observed in the facultative pond in 2003, but in 2004 the actual FWS #1 influent concentrations were approximately the same as those of the facultative pond. Therefore, the estimated values for the FWS #1 influent in 2003 were likely not indicative of actual influent concentrations and hence no assessment of FWS #1 treatment of ammonia could be confidently stated. There was no significant difference observed between the influent and effluent concentrations in any of the other cells, but there was a significant drop in ammonia concentration between the influent of pond and the effluent of FWS #2 (from ANOVA: $f = 4.9 > f_{crit} = 4.3$) indicating that there was ammonia removal within the wetland.

Figure 4.8 demonstrates that the estimated FWS #1 influent nitrogen concentrations did not show the same pattern, with respect to the facultative pond concentrations, as those observed in 2004. This indicates that the estimated concentrations cannot be assumed to be correct. All of the remaining nitrate concentrations were continuously low, demonstrating the ability for the wetland to reduce the nitrate at the same rate as it is formed (from the oxidation of ammonia)

The TKN concentrations only demonstrated a significant decrease in the first cell, but as with the other constituents, this was likely due to the overestimation of the influent constituent concentrations. Since there was no evaluation of TKN in the second year, there was nothing available to corroborate the estimation. Using the estimated influent concentration, the TKN percent removal through the entire wetland was calculated to be 83%. This percent removal followed the increasing trend in TKN removal during wetland maturation. Samples from the 1997 sampling season, while the wetland was young, demonstrated a 67% removal, while samples from 2001 demonstrated a 71% removal (Crolla and Kinsley, 2002). This indicated that the estimation held with the increasing trend in TKN removal, but without a second year of concentration data, there could be no proof that the estimated concentration value was correct.

The BOD₅ concentrations that were estimated for 2003 did not correlate well with the actual values from 2003. Therefore, the treatment in FWS #1 could not be analyzed in the first year. There was no significant reduction of BOD₅ observed in the remainder of the wetland.

Some large differences were seen between the concentration distributions of the first year of the study (Table 4.1), and those of the second year (Table 4.2). The influent

to FWS #1 was returned to the inlet header, such that the data from sampling point “FWS #1 influent” was more accurate and pertinent to the study in the second year.

Table 4.2 Wastewater Constituent Concentrations ($\pm$ 95% CI) in each Wetland Cell (2004)

Constituent	FWS #1 influent	Pond influent	FWS #2 influent	FWS #2 effluent
TSS	89.89 ($\pm$ 79.54)	46.16 ($\pm$ 44.56)	232.80 ($\pm$ 270.32)	76.69 ($\pm$ 90.98)
TP	16.74 ($\pm$ 4.14)	11.38 ($\pm$ 1.35)	11.43 ($\pm$ 1.48)	11.02 ($\pm$ 2.83)
Ammonia	13.36 ($\pm$ 7.07)	10.42 ($\pm$ 5.58)	7.15 ($\pm$ 5.78)	2.10 ($\pm$ 2.43)
Nitrate	1.03 ($\pm$ 0.38)	1.07 ($\pm$ 0.39)	1.07 ($\pm$ 0.42)	1.13 ($\pm$ 0.43)
BOD ₅	149.32 ($\pm$ 77.96)	50.75 ($\pm$ 7.27)	51.10 ($\pm$ 40.25)	53.63 ($\pm$ 26.91)

The TSS concentrations within the cells were erratic, which was most likely due to the re-suspension of sediments, and caused by the shallow wastewater depth, during sampling.

The concentration of TP in the wetland decreased in the first cell (from ANOVA: $f = 5.82 > f_{crit} = 4.96$), but remains constant throughout the remainder of the wetland. This appeared to indicate that the phosphorous removal within the wetland after the first cell had reached a steady state (rate of re-release equal to the rate of uptake). The plants will store the phosphorous and re-release it when they decompose. This coupled with the limited number of sorption sites in the soil and sediment, implies that the phosphorous treatment within the wetland will eventually reach a steady state; a time when the wetland plants will remove the phosphorous released from the decaying plants and not be able to remove any of the phosphorous entering with the wastewater stream. This is best demonstrated by comparing the efficiency of the system for the removal of phosphorous. In the sampling season of the year 1996, the wetland was able to remove an average of

75% of the TP from the influent of FWS #1 to the effluent of FWS #2. In 2000, that efficiency had decreased to an average removal of 49% (Crolla and Kinsley, 2002). This would suggest that the wetland system is nearing a steady state condition with respect to TP removal. The reduction in TP removal efficiency in a mature system would be expected due to the limited number of sorption sites at the commencement of wetland operation being decreased throughout the years of wetland operation. The reduction in TP removal may also be a result of sediments becoming too dense for the wastewater to reach the sorption sites in the soil at the bottom of the cells, or that bacteria have built-up a slime layer covering the sorption sites. Whether the sorption sites have been blocked or they have been used up is difficult to assess without further analysis, but the outcome of these two scenarios are the same, the phosphorous in the wastewater is no longer being removed from the wastewater with the same degree of efficiency as in the initial years of wetland operation.

The removal of ammonia was observed over the entire wetland (from ANOVA: $f = 5.95 > f_{crit} = 5.32$), but the majority of the removal occurred in cells 2 and 3. The nitrate concentrations remained low (as was observed with the 2003 data). The high variability of the BOD_5 concentrations resulted in no observable reduction in concentration throughout the wetland cells.

The overall assessment of the wetland system based on the average concentrations at sampling points throughout the system did not result in marked changes in concentrations throughout the wetland. This was due to the variability of the data, as well as the maturity of the system. The variability of the average concentrations at the sampling points was large enough that ANOVA analysis resulted in very little significant

difference between sampling points. The large variance in concentrations would not be an issue if there were large removals of constituents throughout the cells (as is expected in younger wetlands), but as the wetland has matured, and the removal efficiency of the cells has decreased, this variance has become more important

4.2.3 Removal of Constituents in Wetland Cells

Examining the overall removal within a wetland serves to understand the constituents that can be effectively treated. Separating the wetland further allows the analysis of each separate cell to note the advantages and disadvantages of different types of wetland cells and their configuration. To truly understand the nature of the wetland cells, analyses must be performed at various points throughout the wetland to better understand the effectiveness of all stages. This will lead to a better understanding of the sizing of cells such that land use may be minimized.

4.2.3.1 First Vegetated Cell (FWS #1)

As was stated previously, the influent to FWS #1 was moved from the header to a point source in the first year of the study (2003), but was returned to the header inlet configuration in the second year. The influent pipe was moved to a position along the north side of the first cell between sampling points 3 and 5 (Figure 3.2). This change in input created a situation where sampling points 1, 2 and 3 (Figure 3.2) were located upstream of the influent to the wetland, for this reason, the concentrations were generally lower than expected at these sampling points.

During the two years of study, the vegetation in FWS #1 exhibited some areas where no growth was observed. This lack of plant life could potentially lead to a reduction in plant-mediated treatment. These bald spots were visible in the aerial

photograph from 2003, and were absent in the photograph from 1996 (Appendix A). The bald areas had diminished in size by the second year of the study, but were still present.

The TSS (Figure 4.12) concentrations within FWS #1 were erratic throughout the entire first year of sampling. The random nature of the measured TSS values was discussed in the previous section.

Figure 4.12 TSS Concentrations (±95% CI) in FWS #1 Water Column Samples (2003)

The TP concentrations (Figure 4.13) within the cell remained relatively constant throughout. This demonstrated that steady state conditions had been more than likely attained for TP removal in FWS #1. The sorption sites within the sediment zones have either been exhausted or their access has been blocked by increased sediment density or the formation of a bacterial slime layer; thus there is no removal by sorption. The bald areas of the cell may have added to this steady state by reducing the amount of vegetation

present for plant uptake of available phosphorous, which accounts for a minor portion of the phosphorous removal.

Figure 4.13 TP Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2003)

The ammonia concentrations (Figure 4.14) would appear to demonstrate an increasing trend towards the effluent of the cell at point 8. However, due to the variability of the bi-weekly sample concentrations, there was no notable significant difference in concentrations between the sample points within the cell. Sample points 1 and 2 received negligible quantities of the tracer during the tracer test, and thus lower wastewater constituent concentrations would be expected in these regions, which was observed and is shown in Figure 4.14.

Figure 4.14 Ammonia Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2003)

The nitrate concentrations remained consistently low and, therefore, no significant change in concentration was observed (Appendix B).

The TKN concentrations (Figure 4.15) within the cell appeared to demonstrate an increasing trend from points 5 towards the effluent point 8. This trend was similar to that observed with respect to ammonia as well, since ammonia is one of the forms of nitrogen analyzed as TKN, this was expected. However, the statistical analyses indicated that this trend was not significant most likely due to the variability in the bi-weekly sample concentrations.

Figure 4.15 TKN Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2003)

For the first year (2003) of the study in the first cell, there was a visible correlation between TSS and BOD_5 (Figure 4.16), as the average TSS increased, the average BOD_5 concentration increased as well. The higher BOD_5 concentration at sampling points 5, 6 and 7 was because those were the first points to receive the influent wastes. There was a slight decreasing trend in average BOD_5 concentration towards the effluent at point 8.

Figure 4.16 BOD₅ Concentrations (±95% CI) in FWS #1 Water Column Samples (2003)

In 2004, the header was replaced as the inlet to the wetland, which allowed for the comparison of the two different flow dynamics; point source versus line source.

During the second year of the sampling, the problems associated with sediment disturbance during sampling were also resolved. The sampling mechanism was raised to a shallower depth within the water column. The TSS distribution (Figure 4.17) throughout the cell demonstrated no significant change. The peak at point 3 can be attributed to an anomaly in the data, but unfortunately only one sample could be drawn from point 3 which resulted in an elevated TSS concentration. Further sampling events could have been used to determine if this concentration was incorrect, however a problem with the sampling tube inhibited further sampling. Point 5 resulted in a lower concentration than expected (based on the profile of average concentrations), this will be

discussed in Section 4.3 and could be a result of greater settling area around the sampling station, or a lower flow area.

Figure 4.17 TSS Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2004)

The TP concentrations (Figure 4.18) throughout the cell demonstrated no significant reduction in concentration along the length of the cell. This supported the relatively steady state concentrations measured in the previous year. The bald spots within the cell were diminished in the second year, which implies that there might have been more plants within the cell for the uptake of phosphorous.

Figure 4.18 TP Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2004)

The ammonia concentration distribution within the cell also demonstrated no significant change, due to the variability of the sample concentrations, although the average concentrations appeared to demonstrate a reduction throughout the cell (Figure 4.19). Point 5 demonstrated a peak in ammonia concentration, which could most likely be attributed to a high concentration of birds surrounding that area of the cell. The nitrate concentrations remained low through the entire cell (Appendix B).

Figure 4.19 Ammonia Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2004)

The concentrations of BOD_5 (Figure 4.20) did not change significantly throughout the cell. Point 2 demonstrated the lowest average concentrations along the inlet line of the cell and point 5 had the lowest average concentration within the entire cell. As the TSS concentration was also low at point 5 (Figure 4.17); the lower than expected TSS concentration was probably related to the low organic content at the sampling point.

Figure 4.20 BOD₅ Concentrations ($\pm 95\%$ CI) in FWS #1 Water Column Samples (2004)

Samples were drawn from the sediments during the first year (2003) of the study. The samples were analyzed for nitrogenous species (TKN, ammonia and nitrates) as well as TP. The first observation that can be made about the concentrations in the sediments is that the TP concentrations (Figure 4.21) were generally found to be higher in the water samples, whereas the nitrogenous species concentrations were typically higher in the sediment zones.

Figure 4.21 TP Concentrations ($\pm 95\%$ CI) in FWS #1 Sediment Samples (2003)

The average ammonia concentrations exhibited the similar trends in the sediment (Figure 4.22) and in the water column where the average ammonia concentrations increased towards the effluent (Figure 4.14). The nitrate concentrations were consistently low even in the sediments of the system. The average TKN concentrations (Figure 4.23) increased towards the effluent. The maturation of FWS#1 resulted in a decrease in the removal of all wastewater constituents, overgrowth of plants blocked sunlight from the water surface, phosphorous sorption sites were depleted, or blocked by the high amount of sediments.

Figure 4.22 Ammonia Concentrations ($\pm 95\%$ CI) in FWS #1 Sediment Samples (2003)

Figure 4.23 TKN Concentrations ($\pm 95\%$ CI) in FWS #1 Sediment Samples (2003)

4.2.3.2 Pond Cell (Pond)

The pond cell was only monitored during the first season of the study. The cell was designed as an aerobic pond, a step required for the effective reduction of ammonia concentrations through nitrification. The cell was initially designed to be unvegetated, but as years passed, plant life began invading the cell. This is evident from the two aerial photographs presented in Appendix A. The photograph from 1996 shows the cell just after the commencement of the system, there is no vegetation within the perimeter of the cell. The photograph from 2003 shows that the vegetation has encroached into the pond, thus, reducing the unvegetated area of the cell and changing the treatment dynamics. The vegetation encroaching into the cell blocks wind driven aeration, as well as increases the sediments around the plants through filtration (discussed in Section 4.3).

The majority of the constituents showed a trend of decreasing average concentrations from the northern bank to the southern bank (Appendix A, Figure 3.3). This was primarily due to the point inlet on the northern bank introducing the wastewater such that flow moved directly toward the outlet. The dispersion flow caused the constituents to reach the southern edge of the pond, but the concentrations were much smaller than the concentrations of the bulk flow along the north side of the pond.

The suspended solids (Figure 4.24) exhibited similar average concentration profiles along all three sampling planes. The large surface area of the pond and the slow flow rate are conducive to the settling of solids, therefore, it would be expected, in most situations, for the suspended solids concentrations to decrease. The sunlight and aeration of the pond are perfect for the growth of algae, which tend to be characterized as

suspended solids in laboratory analyses. Algal growth, resulting in suspended solids concentrations remaining constant, is not unusual in natural systems.

INLET			
	I	II	III
	50.33	20.44	32.00
	(±24.69)	(±8.69)	(±18.28)
	IV	V	VI
	46.10	20.11	18.67
	(±21.06)	(±7.48)	(±10.78)
	VII	VIII	IX
	43.93	35.67	22.00
	(±15.05)	(±13.81)	(±7.10)
	OUTLET		

Figure 4.24 TSS Concentrations (±95% CI) in Pond cell Water Column Samples (2003)

The TP concentrations within the cell remained relatively constant (Appendix B), indicating that cell was nearing a steady state with respect to phosphorous removal. This was expected, as there was minimal plant growth in the cell, and the limited sorption zones would be expected to have depleted after nine years of operation. The pond cell was designed to increase the nitrogen removal of the system, but is not expected to have a large effect on TP removal.

Average ammonia concentrations (Figure 4.25) were reduced under the aerobic conditions of the pond. This was seen in the northern section, but the average ammonia concentrations increased as the flow passed further to the south of the cells, however, due to the variability of the samples, there was no statistically significant difference. The increase in ammonia takes place as a result of the conversion of organic nitrogen to ammonia, typically at a faster rate than the ammonia is converted to nitrate.

Figure 4.25 Ammonia Concentrations (±95% CI) in Pond cell Water Column Samples (2003)

A high average nitrate concentration (Figure 4.26) could also be noted along the southern bank, where the corresponding average ammonia concentrations were higher as well. The increased nitrate concentrations indicated that ammonia reduction was occurring within the system; increased ammonia concentrations would appear to suggest that organic nitrogen was being reduced to ammonia at a greater rate than ammonia was oxidized to nitrate.

Figure 4.26 Nitrate Concentrations (±95% CI) in Pond cell Water Column Samples (2003)

The presence of algae can also be responsible for fluctuations in BOD₅ (Figure 4.27). The dead algae would be measured in the same way as other decaying organic matter. The average BOD₅ concentrations in the pond cell demonstrated no notable trend.

INLET			
	I	II	III
	37.97	25.61	27.38
	(±9.23)	(±13.04)	(±12.86)
	IV	V	VI
	44.26	31.52	30.78
	(±12.44)	(±15.86)	(±17.72)
	VII	VIII	IX
	37.26	28.37	24.81
	(±13.61)	(±10.07)	(±8.90)
OUTLET			

Figure 4.27 BOD₅ Concentrations (±95% CI) in Pond cell Water Column Samples (2003)

The sediment zones within the pond cell exhibited an opposite trend from that observed in the water column. The average TP (Figure 4.28) and TKN (Figure 4.31) concentrations increased towards the southern bank along the influent, and while the average TKN concentrations increased towards the south in the effluent, the average TP concentrations decreased towards the south.

Figure 4.28 TP concentrations ($\pm 95\%$ CI) in Pond cell Sediment Samples (2003)

Where the average ammonia concentrations were decreasing towards the southern bank along the inlet in the water column, the ammonia concentrations were increasing towards the southern banks in the sediment samples (Figure 4.29). Where the average nitrate concentrations increased towards the southern banks in the water column, they decreased in the sediment zone (Figure 4.30). As the pond cell matured, the main factor affecting the treatment ability of the cell was the encroachment of vegetation. This encroachment blocked wind aeration, as well as giving zones for sedimentation, which has changed the dynamic of the cell as well as its treatment ability.

Figure 4.29 Ammonia concentrations (±95% CI) in Pond cell Sediment Samples (2003)

Figure 4.30 Nitrate concentrations (±95% CI) in Pond cell Sediment Samples (2003)

Figure 4.31 TKN concentrations ($\pm 95\%$ CI) in Pond cell Sediment Samples (2003)

4.2.3.3 Second Vegetated Cell (FWS #2)

The main purpose of the third cell of the wetland was to filter the effluent from the anoxic pond cell. As was previously stated, a pond cell is an area where conditions are often optimal to promote algal growth, and the algae increases TSS and BOD₅ concentrations. When the BOD₅ and TSS are required to be lower than a standard value, the algae must be removed. As an added advantage, FWS #2 also serves to remove more of the nutrients, resulting in a higher quality effluent.

The TSS (Figure 4.32) and BOD₅ (Figure 4.35) concentrations were again erratic possibly due to the re-suspension of solids during sampling in the first year. The TP concentrations (Figure 4.33) demonstrated no significant change in concentrations throughout in the cell, indicating that the cell was close to steady state conditions (Section 4.3.3.1).

Figure 4.32 TSS Concentrations (±95% CI) in FWS #2 Water Column Samples (2003)

Figure 4.33 TP Concentrations (±95% CI) in FWS #2 Water Column Samples (2003)

Ammonia concentrations (Figure 4.34) also demonstrated no significant change throughout FWS #2, although the average concentrations appeared to demonstrate a decreasing trend from the northern bank to the effluent at the southern corner, but along the southern bank little to no reduction in concentrations were observed. The nitrate concentrations remained consistently low (Appendix B), and the TKN concentrations demonstrated no significant change throughout the cell (Appendix B).

Figure 4.34 Ammonia Concentrations (±95% CI) in FWS #2 Water Column Samples (2003)

Figure 4.35 BOD₅ Concentrations (±95% CI) in FWS #2 Water Column Samples (2003)

In the second year of the study, the average TSS concentrations (Figure 4.36) exhibited a decreasing trend towards the effluent, as was expected. The ammonia concentration (Figure 4.37) demonstrated a significant reduction between point iii and the outlet vi (from ANOVA: $f = 7.42 > f_{crit} = 5.99$). The nitrate and TKN concentrations demonstrated no significant change in concentrations throughout the cell (Appendix B).

Figure 4.36 TSS Concentrations (±95% CI) in FWS #2 Water Column Samples (2004)

Figure 4.37 Ammonia Concentrations (±95% CI) in FWS #2 Water Column Samples (2004)

The average BOD₅ concentrations (Figure 4.38) demonstrate no significant trend in treatment within the cell.

Figure 4.38 BOD₅ Concentrations (±95% CI) in FWS #2 Water Column Samples (2004)

The operation of FWS #2 was the only aspect of the two years that remained under the same flow conditions throughout both years of the study. In FWS #1, the influent distribution method changed in each of the two years. Pond cell was not monitored throughout the second year due to a reduction in resources. FWS #2 remained the same for both years of the study and, the influent and effluent positions did not change. As a result of the similar flow conditions in each year, the concentration profiles from the two years were also very similar. The main difference between the two years was that the measured concentrations were lower in the second year. The influent wastewater to the lagoon was lower in constituent concentrations in the second year, which could account for the lower concentrations throughout FWS #2, this could be due to more precipitation and runoff during the second year.

The sediment zone of FWS #2 demonstrated no significant trend in concentration throughout the cell with respect to TP (Figure 4.39), ammonia (Figure 4.40), nitrate (Figure 4.41) or TKN (Figure 4.42).

Figure 4.39 TP Concentrations (±95% CI) in FWS #2 Sediment Samples (2003)

Figure 4.40 Ammonia Concentrations (±95% CI) in FWS #2 Sediment Samples (2003)

Figure 4.41 Nitrate Concentrations ($\pm 95\%$ CI) in FWS #2 Sediment Samples (2003)

Figure 4.42 TKN Concentrations ($\pm 95\%$ CI) in FWS #2 Sediment Samples (2003)

The trends in average nutrient concentrations, or lack thereof, within the wetland cells are similar to that of a completely mixed system, in that the composition is uniform throughout the entire wetland cell, the accounting may be made of the wetland cell as a whole (Levenspiel, 1999). Although there is little trend of progressive treatment within each of the wetland cells after nine years of operation, there is progressive treatment through the entire wetland system. This indicates that the wetland cells could be behaving as CSTRs, with the vegetation likely aiding in mixing.

Another option for the reason the concentrations within the cells are similar could be that the cells have reached background concentration levels. The reduction in treatment ability of the wetland during maturation might be a result of the increase in background concentration of the wetland throughout the maturation of the system.

4.3 SEDIMENT DEPTH AND VEGETATION DENSITY IN FWS #1

After nine years of operation, the mature wetland was exhibiting some interesting phenomena with respect to the distribution of constituent concentrations. The TP concentrations throughout the wetlands have started to reach a steady state with respect to removal of phosphorous.

Mechanisms for the removal of suspended solids are sedimentation and filtration by the wetland plant media. These sediments accumulate, as the wetland matures, along the floor of the wetland cell and will remain there until dredging of the wetland takes place. FWS #1 receives the highest concentrations of suspended particles and would, therefore, be the first cell that would require the dredging of sediments. At the beginning of the second year of sampling (2004), after the wetland had been operating for nine years, the sediments in the first cell were measured and a simple map of the sediment

depth in FWS #1 was produced (Figure 4.43). The map demonstrates that there are three regions (darkest) where the sediments peaked above the water surface (30 cm). There was also a trend of high sediments along the northern bank of the cell, while the middle and southern bank had lower sediment depths. The separation between the high-depth northern side and the low-depth southern side followed much the same path as would have been expected for the flow from the inlet header to the southern point along the outlet. This trend is seen in the tracer distribution in 2004 (Figure 4.4). Having lower sediment depths through one area and higher depth at another would suggest that preferential pathways and potential localized mixing zones have been established within the cell. Sedimentation occurs at a greater rate as flow velocities decrease; and the higher volumes of sediments are indicative of a lower velocity of flow in those areas. The lower sediment depths indicate higher flow velocities in these regions and, therefore, less sedimentation.

Figure 4.43 Sediment Height (in cm) Within FWS #1 (2004)

Within the assumed preferred flow channel or areas of lower sediment depths, small peaks of deposited sediments and larger localized valleys of lower sedimentation were observed. If the flow were assumed to be moving uniformly through the flow area of the cell and the wastewater were assumed to have a uniform distribution of solids, the sedimentation of solids would be assumed to be uniform through the flow area. These localized peaks and valleys in the sediments can probably be attributed to the filtration of the wastewater by the wetland plants. When Figure 4.43 is compared with Figure 4.44, the peaks and valleys of the sediments can often be found to correspond to the density of vegetation in those areas.

Figure 4.44 Vegetation density (out of 10) in FWS #1 (2004)

The low sediment depth regions that can be seen in Figure 4.43 typically correspond to areas of low vegetation density (Figure 4.44). Increased flow velocity over the sediments leads to re-suspension of some of the smaller and less dense sediments as

well. This would account for the variability in TSS concentrations through the wetland cell. Dredging of the wetland could solve this variability problem, and since the vegetation would require re-planting after the dredging is complete, this new vegetation and the associated new soil layer would increase the potential for the removal of phosphorous. The removal of the vegetation from the cell would also remove the decaying vegetation that releases phosphorous into the system. Thus, the fresh cell would act as a new wetland with respect to the removal of wastewater constituents. However, the areas of increased and decreased flow velocities can also lead to zones of higher mixing intensities, which could help establish completely mixed conditions within the wetland cell.

The sediment distribution demonstrates the potential for localized mixing zones. As the wetland matures, the mixing zones will increase in size and number, as preferential flow pathways increase. These mixing zones will likely impact the entire system, given enough time to evolve, resulting in a complete mixing of the system. This is probably why there are similar concentrations throughout each wetland cell. This mixing within the cells can create a situation where the cells are acting as if they were a completely mixed system.

Since the rates of conversion are greater under plug flow characteristics than under mixed flow characteristics, the reactions will be completed more quickly under plug flow, and therefore plug flow treatment systems would require a smaller volume than mixed flow systems. When the conversion of a constituent is small, flow type only affects the performance slightly, but as the conversion of the constituent increases, the size ratio increases rapidly (Levenspiel, 1999). As the wetland matures, there appears to

be a transition in the flow type, from a plug flow system, which represents the original system design, to a mixed flow system. This change in flow characteristics could possibly be correlated to sedimentation and vegetation growth. When the wind rustles the vegetation, the stalks transfer the motion, thus mixing the wastewater. Increased sediment depths decrease the volume of wastewater flow, thus increasing the flow velocity, which also adds to the mixing of the wastewater within the cell. Dredging the wetland to remove the sediments and vegetation, followed by replanting of the cell, would lower the sediment depths, thus decreasing the flow velocities. Replanting the cell with a lower density of vegetation would result in less mixing due to an increase in space between the stalks.

4.4 ASSESSMENT OF DESIGN MODELS

The analysis of the influent and effluent constituent concentrations from the cells and the comparison to the three existing design models (Kadlec and Knight, 1996; Reed et al., 1995; and Crites and Tchobanoglous, 1998) for constructed wetlands resulted in some significant discrepancies. The calculated rate constants for the nutrients (Table 4.3) did not reflect the values suggest in the literature (DLWC, 1998; CH2M Hill, 1997). For the majority of the cells, the suggested values were higher than the values determined from the Dignard wetland concentrations. All of the rate constants were lower in the wetland than suggested in the literature.

Table 4.3 Calculated Rate Constants Compared to Values from the Literature

		TP	BOD ₅	Ammonia	Nitrates	TKN
Kadlec and Knight (m/yr)	FWS #1 2003	3.12	5.66	7.49	5.53	3.29
	FWS #1 2004	3.255	10.6	2.1	0	---
	FWS #2 2003	2.035	2.67	11.48	-0.4	2.31
	FWS #2 2004	0.355	-0.546	12.18	-0.52	---
	Literature values (CH2M Hill, 1997)	8	22	10	---	14
Reed et al., (yr)	FWS #1 2003	---	19	24.17	19.43	---
	FWS #1 2004	---	0.28	---	0.137	---
	FWS #2 2003	---	0.021	0.112	-0.01	---
	FWS #2 2004	---	-0.004	---	-0.005	---
	Literature values (DLWC, 1998)	---	0.296	1.048	1.15	---
Crites and Tchobanoglous (/yr)	FWS #1 2003	---	7.56	---	---	---
	FWS #1 2004	---	0.095	---	---	---
	FWS #2 2003	---	0.022	---	---	---
	FWS #2 2004	---	-0.004	---	---	---
	Literature values (DLWC, 1998)	---	0.296	---	---	---

The difference between the actual values and the literature values indicated that the wetland was not behaving as the models would predict. The Kadlec and Knight, and Reed, Crites and Middlebrooks models both assume plug flow characteristics, which, as discussed previously, are more efficient than mixed flow characteristics. The Crites and

Tchobanoglous model assumes that the flow within the wetland acts as a series of 4 CSTR's, which result in a more efficient system than a single CSTR, but less efficiently than a plug flow system. Since each of the cells of the Dignard constructed wetland appeared to be behaving like single CSTRs, then it would be anticipated that the wetland cells would be less effective than the models would estimate. The tracer data from Section 4.1 also demonstrated that the wetland was not operating under ideal flow conditions (plug flow with respect to Kadlec and Knight and Reed Crites and Middlebrooks models, mixed reactors in series with respect to the Crites and Tchobanoglous model), which may be one of the causes for the differences in the results.

To better understand how the wetland was behaving differently than the design models, the concentrations at each of the points were analyzed with respect to the models. This analysis better demonstrated the areas within the wetland that behaved as the models predicted, as well as indicated which of the models, that are each based upon different assumptions and criteria, best represent the Dignard wetland treating agricultural wastewaters in the climate of eastern Ontario, Canada.

When the wetland cells were divided into different zones, separated by the retention time of the tracer, some of the models were applicable for different regions of the cell. In order to analyze the concentration distribution throughout the cell with respect to the models, the FWS #1 influent concentrations measured in the first year could not be used. Instead, the influent concentration was estimated due to changes in the inlet, as was discussed in Section 4.2.1. This assumption allowed for the model to be analyzed for its pertinence at the other points within the cell. The model calculations can be found in Appendix D.

4.4.1 TSS Removal

Modeling the TSS removal through the cells did not result in any comparable results of the collected data to the existing models. During the first year of the study (2003), the concentrations varied significantly from sampling session to sampling session and could not be reproduced with model predictions. In the second year of the study (2004), the concentrations were very high at the influent and the actual concentrations within the cell were below the predicted background level, which would indicate that the background concentration calculations from the Kadlec and Knight model were too conservative for the concentrations observed in the Dignard wetland. For this system configuration, the Kadlec and Knight model also results in a drop in TSS values to the background level within one day, which would indicate that the removal of TSS would only occur in the first day of treatment.

4.4.2 TP Removal

The removal of TP within the wetland cells could also not be represented adequately by any of the models, due to the pseudo-steady state conditions that were reached in the Dignard wetland with respect to the treatment of phosphorous. The models assume that there is a high concentration zone within the sediment for the sorption of phosphorous. However, the models do not account for the exhaustion of these sorption sites in a mature wetland which would greatly decrease the ability of the wetland cell to remove phosphorous without dredging, harvesting and re-vegetating of the wetland cell

4.4.3 Ammonia Removal

The ammonia removal throughout the cells of the Dignard wetland was extremely efficient. In most cases, the removal of ammonia was higher than the models predicted

with shorter residence times (<5 days), and the models predicted better removals at higher retention times. In FWS #1, during the first year of the study (with adjusted influent concentrations), a model containing two CSTRs in series (Figure 4.45) resulted in a good fit to the lower concentrations in the cell (using the rate constant suggested for the Reed model; Table 4.3). In the first cell during the second year of the study (Figure 4.46), the Kadlec and Knight model predicted the concentrations well at the higher retention times.

The Reed, Crites and Middlebrooks model utilizes the influent TKN concentration to determine the effluent ammonia concentration and, thus the rate of denitrification. The other two models use influent ammonia concentrations to determine the effluent ammonia concentrations. For this reason, the initial concentrations on the following figures are different for the two models.

Figure 4.45 Ammonia Concentrations in FWS #1 (2003)

Figure 4.46 Ammonia Concentrations in FWS #1 (2004)

In FWS #2, during the first year, the ammonia concentrations were lower than the Reed model predicted (Figure 4.47), but if the rate constant were considered to be a higher value than suggested, the model would provide a good fit to the points within the cell at longer retention times. The Kadlec and Knight model predicted the concentrations at the points with a shorter retention time. The FWS #2 concentration distribution observed in 2004 was far lower than any of the models predicted, and no relations to the models could be observed (Appendix D).

Figure 4.47 Ammonia Concentrations in FWS #2(2003)

4.4.4 Nitrate Removal

Since the nitrate concentrations through the cells were consistently low, the models did not accurately describe the removal of nitrates. All of the models predicted that the nitrate concentrations would be reduced to a value lower than concentrations measured in the cells.

4.4.5 TKN Removal

The TKN concentrations through the cells demonstrated no correlation in trend or magnitude with the concentrations predicted by the models. Therefore no appropriate fit could be made to any of the models. The Models for TKN removal are presented in Appendix D.

4.4.6 BOD₅ Removal

The Crites and Tchobanoglous model (4 CSTRs in series for the removal of BOD₅) predicted well the processes at work in the earlier portions of the cell where the

retention time was less than four days, after 4 days the model did not adequately describe the removal of BOD₅. The Kadlec and Knight and Reed (plug flow) models also worked well for the removal of BOD₅ at a retention time of less than four days.

The models for the design of wetlands may not be applicable to the treatment of wastewater constituents in mature constructed wetlands. As the wetlands mature, the treatment efficiencies decrease with respect to some of the constituents, TSS and TP especially. The flow and treatment dynamics would also be expected to change; uneven sedimentation increases the flow rate and creates flow channels. The mixing induced by these changes in flow, as well as the increased vegetation density creates a treatment dynamic that is more like a single CSTR than a plug flow. The existing models are based on a large database of young wetlands, acting under plug flow conditions, with little to no mature systems. New models need to be developed to better describe the activities within mature systems. These models would need to track the change from the plug flow dynamic to the completely mixed scenario that is observed in the Dignard constructed wetland.

4.5 ENGINEERING SIGNIFICANCE

As wetland systems mature, many changes take place that alter the efficiency and method of treatment. When the wetland is first built, the vegetation is uniformly planted, and the types of species are controlled. The soil at the base of the wetland cells has sorption sites that are available to adsorb phosphorous. There are no sediments from the wastewater that cover the floor of the cell. The bacterial cultures in the water are immature, and there are no insect larvae in the cells. As the wetland matures, all of these conditions change. The vegetation in the cells propagates naturally, which results in an

uneven density of vegetation and different species of vegetation entering the cell. This increased vegetation density results in a larger surface area for bacterial growth, which is good, but also blocks more sunlight and wind driven aeration of the wastewater, which can affect the treatment within the cells. The phosphorous sorption sites begin to become depleted and the removal of phosphorous is decreased. Sediments begin to accumulate on the floor of the wetland cells, further blocking phosphorous sorption to the soils as well as potentially creating flow channels. The sediments also give media for the growth of different bacteria in the system. Bacteria cultures mature along with the wetland, which increases the biological treatment potential of the system.

The tracer concentration distribution and the concentration distribution in each of the cells seemed to indicate that the system was behaving like a completely mixed reactor. This is in opposition to the accepted thought that the wetlands behave as plug flow reactors. However, most of the wetlands that were studied to create the models were young systems (2-3 years old), and the system that was studied was a mature system (9 years old). The kinetic rate constants that were determined for each of the cells of the wetland were different than the rate constants suggested for any of the design models.

Without adequate monitoring of the data from the first year of the wetland operation, it is impossible to know if the wetland originally functioned as a plug flow reactor, and therefore if the dynamics of the system have really changed. Another option would be that the treatment within the cells was quickly reducing the constituent concentrations to background levels, and it is these background levels that are increasing as the wetland matures.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

With the new environmental regulations that are coming into place in Ontario, adequate treatment of agricultural wastewaters must be ensured. Since farmers will have to fund their own onsite treatment systems, as well as any monitoring costs, the system with the least capital and, maintenance and operation costs will be preferred. Constructed wetlands offer a wastewater treatment option that requires minimal construction costs and limited operation and maintenance. The wetland cells will need to be occasionally cleaned (sediments removed and vegetation replanted). From the results of this study, a mature wetland which receives a high organic load wastewater similar to that of the Dignard operation will need to be dredged within approximately eight years of operation. With the field machinery available to a farmer, this should not be a difficult and costly undertaking. Since most conventional wastewater treatment systems are designed for a useful life of twenty years, wetland treatment systems need to demonstrate an equivalent expected lifetime. With occasional dredging and replanting of the wetland cells, the life of the wetland could be extended indefinitely. Increased wastewater flows can also be treated by adding more treatment steps (anaerobic lagoons, facultative ponds or marsh-pond-marsh wetland cells) to the systems.

Observing the activities within the individual cells of a wetland is essential in determining the treatment processes and efficiencies within the wetland system. Analyses of the wetland influents and the effluents will not provide sufficient information to enhance the understanding of these processes. Ideal treatment processes within the wetland require the flow through the wetland to be uniform, which is an unrealistic

assumption in a natural and dynamic system, since there are various factors affecting the flow such as vegetation density, uneven settling, and wind induced turbulence. Dissecting the wetland cells allows for the assessment of the sections of the cells that are useful in the treatment of wastewater constituents, and those that are not. These observations, in turn, can lead to a better understanding and, ultimately, better design of wetland sizing and the prediction of treatment potential.

The tracer study throughout the cells indicated that the flow generally followed the path that would be expected based on the inlet and outlet positions. These flow patterns (CSTR) are not ideal (plug flow) for the treatment of wastewater constituents in a wetland. To improve the flow pattern, and maximize contact with the entire wetland, the outlet conditions should be modified. The flow can be improved by changing the outlet from a point along one of the sides to a series of weirs along the outlet end of the cell, which would induce a sheet flow dynamic over the entire cell. This would better distribute the wastewater stream, which would reduce the number of dead zones within the cell. The reduction of dead zones would mean that preferential flow pathways within the cell would be the only inhibitors to sheet flow dynamics, which would be ideal in wetland design.

The tracer flow through the wetland was useful in explaining the abnormal concentrations within the zones of the wetland that received small amounts of tracer, but the flow path of the tracer could not be correlated to any specific removal pattern within the cell. The tracer distribution and movement throughout the wetland cell did not correlate with the distribution of concentration throughout the cell, which might suggest that the wetland was likely acting as a completely mixed system or has reached

background concentrations. The instantaneous addition of the tracer solution was effective at illustrating the mixing profile within the wetland cells. However, the injection of the tracer solution continuously with the flow of wastewater being added to the wetland system, may be more effective at further defining the mixing profile within the cells. The tracer distribution was also able to support the sedimentation patterns within FWS #1, with respect to the high sedimentation pattern in the lower flow region.

For all of the constituents, in both years of the study, the concentration reduction reached a plateau within the first eight days of flow through the cells, which is when the Kadlec and Knight model demonstrated the best correlation to the actual removal efficiency of the cells. The aerial based Kadlec and Knight design model works best at lower retention times, but the treatment efficiency of the cell generally decreases faster than that expected in the model. The Reed, Crites and Middlebrooks model accounts for the tapering off of treatment efficiency through the cell, but the model is too conservative, for the most part, with respect to the treatment within the first section of the cell. Both the Kadlec and Knight model and the Reed, Crites and Middlebrooks model can be compared with the treatment ability of the Dignard wetland cells, but the rate constants suggested by the literature needed to be altered.

The design models for wetland treatment, which are based on young treatment systems, did not appear to apply to this mature wetland. Designs should ensure sustainability of the wetland treatment systems. New models, which account for the reduction in treatment as the wetland matures, must be developed to ensure that adequate prediction of the wastewater treatment within the system is possible. As a constructed wetland matures, the efficiency for treating wastewater constituents decreases; this may

be the result of the change from a plug flow treatment system to a CSTR treatment system, or the increase in the background concentration of the system.

The concentration distribution at each of the sampling points varied throughout the two years of the study. This variance in constituent concentrations was a result of the weather in the region. In the spring and fall, the rain dilutes the wastewater, resulting in lower concentrations, where as in the summer, high evapotranspiration results in more concentrated wastewater.

5.2 RECOMMENDATIONS FOR FURTHER STUDY

There are several studies that could be performed to better understand the processes within a matured constructed wetland. The results from the tracer study presented in this thesis could be further analyzed with sophisticated computer modeling approaches to take into account dynamic factors such as sedimentation, mixing intensities, possible changing flow regimes, vegetation growth, etc. This type of analysis would generate a better understanding of the actual treatment performance and the dynamics of various factors within the wetland cells. This could then lead to the development of specific model predictions of the treatment performance occurring within mature wetlands.

A study of the hydrodynamic flow and treatment performance throughout the loose sediments of the wetland cells, correlated with the hydrodynamic flow and treatment performance of the surface water may lead to the understanding of which portion of the wetland mediates the treatment of the individual constituents. This could lead to the development of specific rate constants with changing sediment volumes and characteristics. That is, as the wetland matures there is a greater build-up of sediments on

the wetland floor and a greater opportunity of surface water and loose sediment water to interact, and impact overall wetland treatment performance.

Further studies on maturing constructed wetlands are required as the treatment efficiency and flow patterns appear to change significantly throughout the life of the wetland. This would help to generate specific models that will better describe the treatment potential of the wetland system, as well as assist in the determination of important design considerations such as dredging of sediments and, harvesting and re-planting of vegetation, as the system ages.

CHAPTER 6

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APPENDIX A RELATED IMAGES

Figure A-1 Aerial Photograph of Dignard Wetland (1996)

Figure A-2 Aerial Photograph of Dignard Wetland (2003)

Figure A-3 Sieve Placement in Wetland

Figure A-4 Sampling Apparatus

APPENDIX B

RAW DATA

Table B-1 Sample Temperatures (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	28-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std Dev
Lagoon	17.3	no sample	27.7	30.4	25.1	34	27.2	20.1	20.1	19	8	8.7	3.8	20.11667	9.458007
Exercise runoff	14.6	16.4	24.4	24.6	21.4	32	no sample	no sample	no sample	no sample	no sample	no sample	no sample	22.26667	6.319072
Facultative Pond	15.3	18	29.4	28.7	24.6	27.8	28.7	21.6	13.1	19	5.5	9.9	4.2	18.90769	8.875947
Cell 1 Influent	12.1	14.9	21.9	22.1	18.8	16.9	22.1	no sample	9.4	19	2.3	9.7	1.4	14.21667	7.318946
Cell 2 Influent	10	10.8	16.6	25	18.1	18.1	22.2	no sample	10	18.4	2.6	9.7	2.9	13.7	7.140155
Cell 3 Influent	14	15.6	19.6	24.7	19.6	20.6	23.1	23.1	9.9	18.4	4.3	9.5	3.1	15.82308	7.180663
Cell 3 Effluent	11.1	16.9	15.8	21.4	no sample	16.6	21.1	no sample	9.2	17.8	2.6	10.9	2.5	13.26364	6.59792
Filter Strip Runoff	9.3	no sample	16	no sample	no sample	16.6	21.4	no sample	8.3	17.7	2.4	11.7	3.3	11.87778	6.601852
1 Water	no sample	20.3	24.3	25.8	19.4	21.7	24	no sample	11.2	17.9	5.3	no sample	no sample	18.87778	6.69025
1 Sediment	no sample	no sample	no sample	no sample	no sample	23.8	24.6	18.5	18.1	20.7	16.8	no sample	no sample	20.08333	3.570668
2 Water	no sample	22.4	22.2	28.2	19.9	23.7	24.1	no sample	11.3	17.9	5	no sample	no sample	19.41111	7.161781
2 Sediment	no sample	no sample	no sample	no sample	no sample	24.2	no sample	18.9	15.8	20.7	14.8	no sample	no sample	18.88	3.799605
3 Water	no sample	22.7	27.8	19.4	23.5	23.5	24.5	no sample	11.2	18.4	6.6	no sample	no sample	19.2625	7.13341
3 Sediment	no sample	no sample	no sample	no sample	no sample	25.6	23.8	19	15.6	20.8	14.2	no sample	no sample	19.83333	4.478244
4 Water	no sample	21.3	25.3	29.6	19.7	23.9	25.5	no sample	11	16.3	5.5	no sample	no sample	20.01111	7.596289
4 Sediment	no sample	no sample	no sample	no sample	no sample	26.1	24.2	no sample	15.6	20.8	15	no sample	no sample	20.34	4.981767
5 Water	no sample	22.9	24.9	31.98	20.3	25.8	25.8	no sample	14.8	18.2	5.3	no sample	no sample	21.10889	7.734773
5 Sediment	no sample	no sample	no sample	no sample	no sample	25	no sample	18.9	15.5	20.9	15.5	no sample	no sample	19.16	3.99975
6 Water	no sample	22.4	22.8	31.6	27	25.6	26.3	no sample	10.9	18.3	5.8	no sample	no sample	21.18889	8.23733
6 Sediment	no sample	no sample	no sample	no sample	no sample	23.1	26.1	18.7	14.6	20.9	15	no sample	no sample	19.73333	4.539897
7 Water	no sample	21.7	21.7	32.3	23.6	25.8	26.5	no sample	13.9	18.1	5.5	no sample	no sample	21.01111	7.80856
7 Sediment	no sample	no sample	no sample	no sample	no sample	24	25	18.9	14.3	20.8	15	no sample	no sample	19.66667	4.468425
8 Water	no sample	19.3	20	29.6	22.7	24.5	26.6	no sample	10.9	18.6	5.4	no sample	no sample	19.75556	7.624158
8 Sediment	no sample	no sample	no sample	no sample	no sample	24.8	24.6	18.9	14.1	20.7	15	no sample	no sample	19.68333	4.584939
9 Water	no sample	22.3	21.6	29.6	no sample	23.3	26.5	no sample	13.2	19.1	6	no sample	no sample	20.2	7.520258
9 Sediment	no sample	no sample	no sample	no sample	no sample	25.1	25	18.6	13.8	20.8	16	no sample	no sample	19.88333	4.646899
I Water	no sample	22	26.1	27.3	25	21.6	24.9	17.6	13.1	18.5	5.7	12.1	no sample	19.44545	6.82061
I Sediment	no sample	no sample	no sample	no sample	no sample	23	26.4	20.5	15	20.9	16	15.2	no sample	19.57143	4.354582
II Water	no sample	21.2	28.5	26.7	25.4	21.7	24.7	17.7	13	18.8	15.5	10.2	no sample	20.30909	5.8625
II Sediment	no sample	no sample	no sample	no sample	no sample	23.2	25.8	20.4	15.6	20.9	15.5	no sample	no sample	20.23333	4.102032
III Water	no sample	22.7	28	28.9	27.4	21.6	24.6	18.4	12.7	18.6	no eval	11.3	no sample	21.44	6.157416
III Sediment	no sample	no sample	no sample	no sample	no sample	23.6	25.5	20.2	15.6	20.9	14.5	15.4	no sample	19.38571	4.324129
IV Water	no sample	20.5	25.9	28.8	28.6	21.7	24.7	19.2	12.6	18.8	15	12	no sample	20.70909	5.930844
V Water	no sample	22	28.6	28	28.4	21.8	25.6	19.5	12.7	19.3	5.9	12.4	no sample	20.38182	7.457321
VI Water	no sample	24.2	28	27.2	28.8	21.6	25	19.1	12.5	18.9	6	12.4	no sample	20.33636	7.411245
VII Water	no sample	20.5	27	26.6	28.1	21.1	24.9	17	12.3	8.5	5.7	12.6	no sample	18.57273	7.880494
VII Sediment	no sample	no sample	no sample	no sample	no sample	23.2	26.2	19.9	15.3	20.8	15	no sample	no sample	20.06667	4.390748
VIII Water	no sample	20.4	25.5	26.2	27.5	20.8	25.2	17.2	12.1	19.4	5.8	12.4	no sample	19.31818	6.911413
VIII Sediment	no sample	no sample	no sample	no sample	no sample	23.2	26.1	20.6	15	20.7	15	no sample	no sample	20.1	4.432606
IX Water	no sample	21.4	27.8	26.1	28.5	20.8	24.7	18.3	12.2	19.8	5.5	13.7	no sample	19.70909	7.201174
IX Sediment	no sample	no sample	no sample	no sample	no sample	23.6	26	20.2	15.4	20.6	15	no sample	no sample	20.13333	4.368371
i Water	no sample	20.9	27.1	22	no sample	no eval	22.7	no sample	8.6	19.7	10.3	13.9	no sample	18.15	6.508017
i Sediment	no sample	no sample	no sample	no sample	no sample	23.6	23.7	18.7	14.1	20.5	no sample	15.2	no sample	19.3	4.086563
ii Water	no sample	21.2	27.4	21.9	no sample	no eval	22.9	no sample	8.6	19.4	8	13.6	no sample	17.875	7.044501
ii Sediment	no sample	no sample	no sample	no sample	no sample	24.3	23.3	18.6	14.3	20.8	no sample	15.2	no sample	19.38333	4.121852
iii Water	no sample	22.8	28.9	21.3	no sample	no eval	23.4	no sample	9	18.7	no sample	13.3	no sample	19.62857	6.669761
iii Sediment	no sample	no sample	no sample	no sample	no sample	24.6	24.1	18.4	14.4	20.7	no sample	15.4	no sample	19.6	4.303022
iv Water	no sample	21.3	25.2	21.4	no sample	no eval	22.7	no sample	9	20	no sample	13.5	no sample	19.01429	5.692518
iv Sediment	no sample	no sample	no sample	no sample	no sample	26.7	24	18.3	15.1	20.8	no sample	15.7	no sample	20.1	4.622986
v Water	no sample	20.8	27	21.3	no sample	no eval	23.3	no sample	8.8	19.8	6.4	13.5	no sample	17.6125	7.263497
v Sediment	no sample	no sample	no sample	no sample	no sample	25.3	23.3	18.1	14.8	20.8	no sample	15.5	no sample	19.63333	4.235878
vi Water	no sample	18.4	23.8	21.5	no sample	no eval	22.6	no sample	9	19.1	9.8	13.1	no sample	17.1625	5.79481
vi Sediment	no sample	no sample	no sample	no sample	no sample	24.7	24.1	18.2	14.7	20.8	no sample	15.6	no sample	19.68333	4.233871
vii Water	no sample	20.9	26.3	20.5	no sample	no eval	22.6	no sample	14.4	20.1	0.5	13.6	no sample	17.3625	7.96814
vii Sediment	no sample	no sample	no sample	no sample	no sample	23.9	23.7	18.3	14.6	20.8	no sample	15.8	no sample	19.48333	3.93315
viii Water	no sample	19.4	25.9	21.3	no sample	no eval	22.6	no sample	13.4	20.2	0.4	14.9	no sample	17.2625	7.905141
viii Sediment	no sample	no sample	no sample	no sample	no sample	25	23.9	18.2	14.5	20.6	no sample	16.3	no sample	19.75	4.180311

Table B-2 Sample Temperatures (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std Dev	Maximum	Minimum
Lagoon	14.2	no eval	22	22	24.3	23	21.1	3.971146	24.3	14.2
Exercise runoff	14.7	31.6	19.2	19.4	22.8	21	21.45	5.654644	31.6	14.7
Facultative Pond	15	30.1	21	21.7	24.6	24	22.73333	4.964541	30.1	15
Cell 1 Influent	12.1	26.1	18	18.3	19	17	18.41667	4.504849	26.1	12.1
Cell 2 Influent	11.5	26.3	17	16.3	19.7	17	17.96667	4.876748	26.3	11.5
Cell 3 Influent	11.9	27.7	16.1	16.1	19.9	16.8	18.08333	5.357767	27.7	11.9
Cell 3 Effluent	12	32.3	14.6	no sample	18.8	15	18.54	8.065854	32.3	12
Filter Strip Runoff	11.2	25.1	15	no sample	19.6	dry	17.725	5.99743	25.1	11.2
1 _w	no sample	19.5	16	dry	tracer	18.4	17.96667	1.789786	19.5	16
2 _w	no sample	19.7	16	dry	tracer	18	17.9	1.852026	19.7	16
3 _w	no sample	dry	dry	dry	tracer	18.6	18.6	#DIV/0!	18.6	18.6
4 _w	no sample	dry	18	dry	tracer	18	18	#DIV/0!	18	18
5 _w	no sample	22.7	16.9	17.5	tracer	tracer	19.03333	3.189566	22.7	16.9
6 _w	no sample	22.7	16.3	17	tracer	tracer	18.66667	3.510461	22.7	16.3
7 _w	no sample	23.9	15.7	17.2	tracer	tracer	18.93333	4.366158	23.9	15.7
8 _w	no sample	25.1	16	16.4	tracer	tracer	19.16667	5.142308	25.1	16
9 _w	no sample	25.7	16	17.2	tracer	tracer	19.63333	5.288037	25.7	16
1 _{sw}	no sample	26.6	tracer	16.5	18.7	17.2	19.75	4.657968	26.6	16.5
1 _{sw}	no sample	27.9	tracer	16.3	18.8	17.1	20.025	5.352492	27.9	16.3
1 _{sw}	no sample	28.1	tracer	16.3	19.1	17	20.125	5.448165	28.1	16.3
1 _{sw}	no sample	27.7	tracer	15.9	18.7	17.3	19.9	5.324159	27.7	15.9
1 _{sw}	no sample	29.7	tracer	16.2	dry	17.3	21.06667	7.496888	29.7	16.2
1 _{sw}	no sample	26.7	tracer	15.9	19	17.6	19.8	4.771443	26.7	15.9
1 _{sw}	no sample	28.2	tracer	16.3	19.1	18	20.4	5.326037	28.2	16.3
1 _{sw}	no sample	dry	tracer	16.2	19.7	17.6	17.83333	1.761628	19.7	16.2

Table B-3 Sample pH (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std Dev
Exercise runoff	7.36	no sample	6.16	7.74	8.7	7.95	8.18	8.02	8.11	7.94	7.8	8.19	7.5	7.804167	0.62302
Facultative Pond	7.37	7.96	8.31	8.35	8.56	9.08	no sample	no sample	no sample	no sample	no sample	no sample	no sample	8.268333	0.569611
Cell 1 Influent	7.79	8.2	8.39	9.08	7.93	8.64	9.09	8.32	7.89	8.17	8.3	8.52	7.9	8.324815	0.423195
Cell 2 Influent	7.42	7.51	7.88	7.47	7.48	7.61	7.4	no sample	7.64	7.91	7.8	7.27	7	7.5325	0.25978
Cell 3 Influent	7.4	7.26	7.51	7.9	7.39	7.95	7.52	no sample	7.81	8.01	7.7	7.42	7	7.5725	0.306331
Cell 3 effluent	7.7	8.58	8.39	8.63	8.72	8.43	7.79	8.09	8.01	8.01	8	7.95	7.7	8.153846	0.355423
Filter Strip Runoff	7.2	7.85	7.1	7.23	no sample	7.59	7.48	no sample	7.66	7.82	7.5	7.66	7	7.460909	0.290154
	6.98	no sample	7.3	no sample	no sample	7.6	7.59	no sample	7.54	7.82	7.3	7.58	7.1	7.423333	0.270647
1 Water	no sample	7.18	7.46	7.19	7.23	7.24	7.22	no sample	7.65	7.4	7.2	no sample	no sample	7.307778	0.161615
1 Sediment	no sample	no sample	no sample	no sample	no sample	8.12	7.32	6.84	7.8	6.97	6.92	no sample	no sample	7.328333	0.525906
2 Water	no sample	7.15	7.26	7.1	7.26	7.08	7.19	no sample	7.9	7.2	7.3	no sample	no sample	7.271111	0.247156
2 Sediment	no sample	no sample	no sample	no sample	no sample	8.03	no sample	6.84	7.97	6.95	6.93	no sample	no sample	7.344	0.60065
3 Water	no sample	7.22	7.09	7.26	7.08	7.08	no sample	no sample	7.52	7.24	7.5	no sample	no sample	7.27125	0.183658
3 Sediment	no sample	no sample	no sample	no sample	no sample	8.04	7.56	7.03	8.13	7.34	7.15	no sample	no sample	7.541667	0.458407
4 Water	no sample	7.04	7.99	7.12	6.9	7.19	7.21	no sample	7.71	7.56	7.2	no sample	no sample	7.324444	0.352956
4 Sediment	no sample	no sample	no sample	no sample	no sample	7.9	7.59	no sample	7.87	7.22	7.08	no sample	no sample	7.532	0.372384
5 Water	no sample	6.82	7.91	7.2	7.15	7.27	7.27	no sample	8.04	7.47	7.2	no sample	no sample	7.37	0.383927
5 Sediment	no sample	no sample	no sample	no sample	no sample	7.93	no sample	6.98	7.75	7.32	7.02	no sample	no sample	7.4	0.427376
6 Water	no sample	7.39	7.35	7.25	7.4	7.36	7.39	no sample	7.87	7.41	7.3	no sample	no sample	7.413333	0.178955
6 Sediment	no sample	no sample	no sample	no sample	no sample	7.86	7.97	7.42	7.79	7.37	7.38	no sample	no sample	7.631667	0.271398
7 Water	no sample	6.75	6.99	6.69	6.96	7.02	7.33	no sample	8.02	7.28	7.5	no sample	no sample	7.171111	0.414561
7 Sediment	no sample	no sample	no sample	no sample	no sample	7.97	7.43	7	8.08	7.04	6.97	no sample	no sample	7.415	0.502265
8 Water	no sample	7.29	7.41	7.01	7.33	7.71	7.44	no sample	7.95	7.72	7.3	no sample	no sample	7.482222	0.284376
8 Sediment	no sample	no sample	no sample	no sample	no sample	8.19	7.34	6.99	7.96	7.27	7.09	no sample	no sample	7.473333	0.48788
9 Water	no sample	7.23	6.63	8.84	no sample	7.6	7.61	no sample	8.05	7.9	7.4	no sample	no sample	7.4075	0.491579
9 Sediment	no sample	no sample	no sample	no sample	no sample	7.93	7.72	7.17	7.64	7.04	7.04	no sample	no sample	7.423333	0.387229
I Water	no sample	8.61	7.63	7.08	8.63	7.45	8	7.38	7.54	7.86	7.9	8.1	no sample	7.834545	0.488802
I Sediment	no sample	no sample	no sample	no sample	no eval	8.42	8.43	8.12	8.12	8.04	7.81	7.5	no sample	8.053333	0.359537
II Water	no sample	8.54	7.24	7.14	7.26	7.33	7.62	7.69	7.54	7.82	8.02	7.99	no sample	7.653636	0.420791
II Sediment	no sample	no sample	no sample	no sample	no eval	7.66	8.14	7.98	7.76	7.67	no sample	no sample	no sample	7.842	0.210523
	no sample	8.42	6.97	7.13	7.33	7.32	7.68	7.61	7.67	7.83	8.06	7.97	no sample	7.635455	0.429007
III Sediment	no sample	no sample	no sample	no sample	no eval	7.7	7.67	7.46	7.58	7.62	7.39	no sample	no sample	7.57	0.121655
IV Water	no sample	8.58	8.14	7.13	7.64	7.51	7.66	8.02	7.54	8.05	8.08	8.12	no sample	7.879091	0.397076
V Water	no sample	8.58	7.17	7.13	7.27	7.36	7.79	7.56	7.42	7.5	7.8	8.05	no sample	7.602727	0.430722
VI Water	no sample	8.31	7.04	7.17	7.29	7.39	7.73	7.48	7.5	7.78	7.7	7.94	no sample	7.575455	0.365441
VII Water	no sample	8.57	7.47	7.21	7.42	7.48	7.82	7.99	7.62	8	7.9	8.04	no sample	7.774545	0.382893
VII Sediment	no sample	no sample	no sample	no sample	no eval	8.49	8.44	8.12	7.7	7.56	no sample	no sample	no sample	8.062	0.422043
VIII Water	no sample	8.52	7.34	7.22	7.3	7.38	7.85	7.54	7.58	7.83	7.9	8.07	no sample	7.684545	0.393506
VIII Sediment	no sample	no sample	no sample	no sample	no eval	7.63	7.25	7.21	7.3	7.15	no sample	no sample	no sample	7.308	0.188202
IX Water	no sample	7.85	6.74	7.11	7.12	7.28	7.84	7.56	7.41	7.81	7.8	7.86	no sample	7.490909	0.387542
IX Sediment	no sample	no sample	no sample	no sample	no eval	7.49	7.71	7.26	7.38	7.28	no sample	no sample	no sample	7.424	0.184201
i Water	no sample	7.04	7.01	7.21	no sample	7.8	1.29	no sample	7.89	7.82	7.98	7.7	no sample	7.482222	0.357763
i Sediment	no sample	no sample	no sample	no sample	no sample	7.84	7.51	6.84	7.64	6.97	no sample	6.85	no sample	7.275	0.440579
ii Water	no sample	6.9	7.01	7.09	no sample	7.52	7.65	no sample	7.75	7.51	8.08	7.36	no sample	7.43	0.381707
ii Sediment	no sample	no sample	no sample	no sample	no sample	8.28	7.42	6.93	7.82	7.09	no sample	6.88	no sample	7.403333	0.554713
iii Water	no sample	7.83	6.93	7.12	no sample	7.41	7.63	no sample	7.38	7.5	no sample	7.49	no sample	7.38625	0.245586
iii Sediment	no sample	no sample	no sample	no sample	no sample	8.41	7.55	7.16	8.07	7.25	no sample	7.12	no sample	7.593333	0.533991
iv Water	no sample	7.04	6.9	6.93	no sample	7.13	7.16	no sample	7.84	7.66	no sample	7.84	no sample	7.3125	0.400812
iv Sediment	no sample	no sample	no sample	no sample	no sample	8.16	7.51	6.95	7.86	6.9	no sample	6.89	no sample	7.378333	0.549742
v Water	no sample	7.38	7.08	7.07	no sample	7.39	7.72	no sample	7.94	7.7	7.94	7.66	no sample	7.542222	0.330332
v Sediment	no sample	no sample	no sample	no sample	no sample	8.78	7.56	7.04	7.71	6.96	no sample	6.96	no sample	7.501667	0.704398
vi Water	no sample	7.19	7.25	7.51	no sample	7.73	7.33	no sample	7.82	7.65	8.1	7.59	no sample	7.574444	0.292323
vi Sediment	no sample	no sample	no sample	no sample	no sample	7.86	7.48	7.02	7.87	6.91	no sample	6.98	no sample	7.353333	0.444237
vii Water	no sample	7.27	7.1	7.12	no sample	7.55	7.65	no sample	7.96	7.58	7.8	7.82	no sample	7.538889	0.312067
vii Sediment	no sample	no sample	no sample	no sample	no sample	8.07	7.75	7.7	8	6.96	no sample	6.93	no sample	7.568333	0.503167
viii Water	no sample	19.4	7.46	7.12	no sample	7.46	7.4	no sample	7.85	7.35	7.8	7.77	no sample	8.845556	3.965174
viii Sediment	no sample	no sample	no sample	no sample	no sample	7.93	7.25	7.01	7.9	7.04	no sample	6.91	no sample	7.34	0.459042

Table B-4 Sample pH (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std Dev
Lagoon	7.36	7	7.72	7.68	7.7	8.02	7.58	0.352817
Exercise runoff	7.85	7.94	7.9	8.1	7.56	7.98	7.883333	0.181815
Facultative Pond	8.08	8.01	7.95	8.17	8.55	8.55	8.218333	0.267164
Cell 1 Influent	7.5	7.66	7.58	6.99	7.35	7.15	7.3716667	0.260109
Cell 2 Influent	7.34	7.41	7.44	7.3	7.38	7.09	7.3266667	0.126122
Cell 3 Influent	7.31	7.62	7.71	7.29	7.27	6.85	7.3416667	0.304527
Cell 3 effluent	7.03	7.36	7.33	no sample	7.25	7.1	7.214	0.143979
Filter Strip Runoff	7.23	7.25	7.48	no sample	7.29	dry	7.3125	0.114419
1w	no sample	7.58	7.13	dry	tracer	7.02	7.2433333	0.296704
2w	no sample	7.1	7.17	dry	tracer	7.36	7.21	0.134536
3w	no sample	dry	dry	dry	tracer	7.05	7.05	#DIV/0!
4w	no sample	dry	7.46	dry	tracer	tracer	7.46	#DIV/0!
5w	no sample	7.1	7.06	6.96	tracer	tracer	7.04	0.072111
6w	no sample	7.37	7.21	7.24	tracer	tracer	7.2733333	0.085049
7w	no sample	7.11	7.19	7.06	tracer	tracer	7.12	0.065574
8w	no sample	7.39	7.22	7.48	tracer	tracer	7.3633333	0.132035
9w	no sample	7.29	7.34	7.1	tracer	tracer	7.2433333	0.126623
1w	no sample	7.12	tracer	7.19	7.16	7.09	7.14	0.04397
11w	no sample	6.94	tracer	7.11	6.93	7.1	7.02	0.098319
11w	no sample	7.35	tracer	7.16	7.22	7.11	7.21	0.103602
11w	no sample	7.06	tracer	7.05	7.26	7.07	7.11	0.100333
11w	no sample	7.44	tracer	7.08	dry	7.32	7.28	0.183303
11w	no sample	7.17	tracer	7.42	7.18	7.08	7.2125	0.145459
11w	no sample	7.11	tracer	7.19	7.38	7.17	7.2125	0.116726
11w	no sample	dry	tracer	7.31	7.44	7.22	7.3233333	0.110604

Table B-5 Sample Dissolved Oxygen Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std. Dev.
Lagoon	outlier	no sample	0	0.09	outlier	0.09	0.02	no probe	0	0	0	0	0	0.02222	0.03898
Exercise runoff	1.46	0	0	7.06	3.15	12.47	no sample	no probe	no sample	no sample	0	0	0	4.02333	4.904596
Facultative Pond	1.34	5.5	0	no value	outlier	3.5	6.1	no probe	0	0	0.15	0	0.4	1.699	2.422627
Cell 1 Influent	1.5	1.89	0	3.62	2.23	1.6	0	no probe	0.5	0	3.34	0.44	2.02	1.428333	1.266971
Cell 2 Influent	1.86	0	0	outlier	2.2	0.7	0.15	no probe	0.08	0	2.56	0.27	2.74	0.96	1.132034
Cell 3 Influent	7	11.17	0	11.8	3.72	3.2	0	no probe	0.87	0	3.57	1.05	4.29	3.889167	4.140578
Cell 3 effluent	3.87	5	0	1.59	no sample	2.33	0	no probe	1.65	0	2.9	1.15	3.97	2.041818	1.740418
Filter Strip Runoff	2.5	no sample	0	no sample	no sample	1.9	0	no probe	0.81	0	4.37	1.27	4.83	1.742222	1.845154
1 Water	no sample	4.65	2.02	1.35	1.51	6.95	2.6	no probe	5.2	0	0.72	no sample	no sample	2.777778	2.317918
1 Sediment	no sample	no sample	no sample	no sample	no sample	5.3	5.01	no probe	5.45	6.4	1.49	no sample	no sample	4.73	1.846888
2 Water	no sample	5.63	0.27	1.25	0.83	5.93	1.66	no probe	6.53	0	0.78	no sample	no sample	2.52	2.686666
2 Sediment	no sample	no sample	no sample	no sample	no sample	4.6	no sample	no probe	4.51	0.54	3.95	no sample	no sample	3.4	1.928229
3 Water	no sample	no sample	0.55	1.7	3.53	7.5	4.56	no probe	6.93	0.07	0.94	no sample	no sample	3.2225	2.891721
3 Sediment	no sample	no sample	no sample	no sample	no sample	3.9	4.99	no probe	6.72	7.2	3.95	no sample	no sample	5.352	1.540412
4 Water	no sample	2.7	6.34	0.68	2.16	3.78	3.07	no probe	6.98	0	1.36	no sample	no sample	3.01	2.325509
4 Sediment	no sample	no sample	no sample	no sample	no sample	4.54	4.85	no probe	6.05	5.91	0.42	no sample	no sample	4.354	2.29426
5 Water	no sample	2.9	1.13	0.72	4.6	7.4	2.29	no probe	7.43	0	0.37	no sample	no sample	2.962222	2.866788
5 Sediment	no sample	no sample	no sample	no sample	no sample	4.6	no sample	no probe	4.99	7.08	2.39	no sample	no sample	4.765	1.921605
6 Water	no sample	3.9	0.26	0.45	5.23	6.36	2.54	no probe	6.85	0	1.47	no sample	no sample	3.066667	2.679933
6 Sediment	no sample	no sample	no sample	no sample	no sample	4.76	3.57	no probe	9.53	7.62	no eval	no sample	no sample	6.37	2.706794
7 Water	no sample	2.38	0.27	0.79	3.93	8.39	2.44	no probe	5.85	0	2.13	no sample	no sample	2.908889	2.755828
7 Sediment	no sample	no sample	no sample	no sample	no sample	3.48	3.61	no probe	5.68	5.04	1.7	no sample	no sample	3.902	1.546488
8 Water	no sample	2.3	0.39	0.51	4.56	8.5	1.99	no probe	6.54	0	0.2	no sample	no sample	2.776667	1.084814
8 Sediment	no sample	no sample	no sample	no sample	no sample	4.36	3	no probe	0.06	5.05	2.48	no sample	no sample	2.99	1.93427
9 Water	no sample	4	2.49	0.75	no sample	8.58	2.62	no probe	7.44	0	1.88	no sample	no sample	3.495	3.058926
9 Sediment	no sample	no sample	no sample	no sample	no sample	3.99	3.82	no probe	6.61	3.32	no eval	no sample	no sample	4.385	1.508432
I Water	no sample	9.9	0.29	6.9	2.99	5.22	0.65	no probe	5.84	no eval	0	6.27	4.22	4.228	3.245204
I Sediment	no sample	no sample	no sample	no sample	no sample	4.59	4.68	no probe	no eval	no eval	0	no eval	no sample	4.635	0.06364
II Water	no sample	8.7	0.15	5.96	5.8	4.92	1.02	no probe	4.41	no eval	0	0.76	no sample	4.359	3.067621
II Sediment	no sample	no sample	no sample	no sample	no sample	3.72	4.35	no probe	no eval	no eval	0	no eval	no sample	4.035	0.445477
III Water	no sample	9.3	3.44	5.18	6.25	4.1	1.29	no probe	5.48	0	1.44	1.84	no sample	3.833	2.816389
III Sediment	no sample	no sample	no sample	no sample	no sample	4.26	5.87	no probe	7.93	3	8.93	1.45	no sample	5.24	2.884136
IV Water	no sample	8.5	0.99	5.09	4.9	5.11	0.6	no probe	4.43	0	1.99	3.28	no sample	3.489	2.629586
V Water	no sample	9.1	0.35	6.73	5.01	4.06	2	no probe	3.72	0	3.66	2.42	no sample	3.705	2.781471
VI Water	no sample	7.15	0.15	6.58	5.35	6.01	0.8	no probe	5.78	0	5.68	1.79	no sample	3.929	2.873799
VII Water	no sample	8.15	0.29	6.8	5.1	5.6	0.5	no probe	2.83	0	no eval	1.02	no sample	3.365556	3.119377
VII Sediment	no sample	no sample	no sample	no sample	no sample	2.45	3.44	no probe	no eval	no eval	0	no sample	no sample	2.945	0.700036
VIII Water	no sample	8	0.31	6.37	5.05	5.5	1.3	no probe	3.51	no eval	0	no eval	0.85	3.432222	2.939744
VIII Sediment	no sample	no sample	no sample	no sample	no sample	3.66	4.55	no probe	7.12	3.67	2.86	no sample	no sample	4.372	1.648414
IX Water	no sample	6.87	6.88	5.66	2.4	4.42	1.03	no probe	6.18	0	no eval	1.36	no sample	3.866667	2.701995
IX Sediment	no sample	no sample	no sample	no sample	no sample	3.04	3.05	no probe	7.85	5.56	6.64	no sample	no sample	5.228	2.151156
X Water	no sample	3.05	2.17	1.78	no sample	6.42	2.05	no probe	7.78	0	no eval	2.06	no sample	3.16375	2.599346
X Sediment	no sample	no sample	no sample	no sample	no sample	4.8	4.53	no probe	2.44	0.96	no sample	2.38	no sample	3.022	1.615401
XI Water	no sample	1.4	1.2	2.31	no sample	6.44	2.49	no probe	6.59	1.36	no eval	0.16	no sample	2.74375	2.434508
XI Sediment	no sample	no sample	no sample	no sample	no sample	4.9	3.85	no probe	6.6	1.99	no sample	2.09	no sample	3.882	1.950479
XII Water	no sample	7	2.59	2.32	no sample	6.45	1.82	no probe	6.26	0.13	no sample	0	no sample	3.32125	2.852675
XII Sediment	no sample	no sample	no sample	no sample	no sample	4.06	2.68	no probe	6.24	5.94	no sample	1.56	no sample	4.096	2.026988
XIII Water	no sample	4.3	0.53	1.9	no sample	6.9	2	no probe	5.95	0	no sample	1.38	no sample	2.87	2.546779
XIII Sediment	no sample	no sample	no sample	no sample	no sample	4.24	2.32	no probe	6.94	0	no sample	3.22	no sample	3.344	2.548545
XIV Water	no sample	8.4	2.63	1.7	no sample	6.75	1.6	no probe	6.84	0	no eval	0.4	no sample	3.825	2.974149
XIV Sediment	no sample	no sample	no sample	no sample	no sample	4.2	3.16	no probe	5.76	3.3	no sample	1.93	no sample	3.67	1.420704
XV Water	no sample	3.02	2.91	3.45	no sample	6.1	1.45	no probe	6.88	0	no eval	0.57	no sample	3.0475	2.454289
XV Sediment	no sample	no sample	no sample	no sample	no sample	4.44	4.57	no probe	6.52	1.35	no sample	1.75	no sample	3.726	2.15514
XVI Water	no sample	6.15	2.9	no sample	no sample	6	1.33	no probe	6.91	0	no eval	2.52	no sample	3.5625	2.501564
XVI Sediment	no sample	no sample	no sample	no sample	no sample	4.28	3.6	no probe	7.45	2.25	no sample	3.37	no sample	4.19	1.963403
XVII Water	no sample	5.36	3.21	0.5	no sample	6.1	1.36	no probe	5.72	1.07	no sample	0.87	no sample	3.02375	2.385042
XVII Sediment	no sample	no sample	no sample	no sample	no sample	4.15	2.02	no probe	4.83	0.19	no sample	4.07	no sample	3.052	1.914372

Table B-6 Sample Dissolved Oxygen Concentrations (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std. Dev.
Lagoon	outlier	0	0	0	0	0	0	0
Exercise runoff	3.13	4.19	0	0	0.9	0	1.37	1.838565
Facultative Pond	0.02	0	0	0	1.87	0.9	0.465	0.77588
Cell 1 Influent	0	0	0	0	0	0	0	0
Cell 2 Influent	outlier	0	0	0	0	0	0	0
Cell 3 Influent	1.05	1.01	2.31	0	0	0	0.7283333	0.924758
Cell 3 effluent	1.8	2.29	0.28	no sample	0	0	0.874	1.088935
Filter Strip Runoff	1.46	1.56	1.3	no sample	0.62	dry	1.235	0.423753
1 _w	no sample	0.31	0	dry	tracer	0	0.1033333	0.178979
2 _w	no sample	0.3	0	dry	tracer	0	0.1	0.173205
3 _w	no sample	dry	0	dry	tracer	0	0	0
4 _w	no sample	dry	dry	dry	tracer	tracer	#DIV/0!	#DIV/0!
5 _w	no sample	0.51	0	1.4	tracer	tracer	0.6366667	0.708543
6 _w	no sample	0.06	0	1.36	tracer	tracer	0.4733333	0.788462
7 _w	no sample	0.4	0	1.51	tracer	tracer	0.6366667	0.782326
8 _w	no sample	0	0	3.69	tracer	tracer	1.23	2.130422
9 _w	no sample	4.92	0	2.06	tracer	tracer	2.3266667	2.470816
1 _{sw}	no sample	2.72	tracer	4.16	0	1.25	2.0325	1.802061
1 _{ss}	no sample	0.15	tracer	3.24	0.87	1.7	1.49	1.327479
11 _{sw}	no sample	2.26	tracer	2.7	2.49	2.11	2.39	0.259101
11 _{ss}	no sample	2.18	tracer	2.85	1.47	1.81	2.0775	0.591009
14 _{sw}	no sample	2.94	tracer	3.03	dry	3.16	3.0433333	0.110604
14 _{ss}	no sample	1.8	tracer	2.72	0	0	1.13	1.357792
17 _{sw}	no sample	1.68	tracer	3.91	1.28	2.7	2.3925	1.175113
17 _{ss}	no sample	dry	tracer	4.34	2.88	1.76	2.9933333	1.293728

Table B-7 Sample TSS Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std Dev
Lagoon	550	no sample	outlier	1232.14	1120	1150	500	410	772.7	1316.67	outlier	918.18	614.2	692.6544	334.0402
Exercise runoff	29	180	954	583.333	550	893	no sample	no sample	no sample	no sample	no sample	no sample	no sample	632.0666	310.323
Facultative Pond	33	83	345	269.565	320	563	390	515	646.1	271.43	71.8	230.77	492	349.8054	180.5297
Cell 1 Influent	37	163	43	70	320	517	280	no sample	73	678.13	973.9	800	1176.9	463.1755	395.0094
Cell 2 Influent	109	419	179	93.589	60	433	460	no sample	14	98	284	45	170.6	205.1081	166.6951
Cell 3 Influent	58	46	96	146	outlier	180	75	174	162.6	173	82	121.11	156	129.2464	47.44844
Cell 3 effluent	14	230	46	outlier	no sample	54	148	no sample	1	18	42	27	156.6	80.28889	78.3907
Filter Strip Runoff	96	no sample	87	no sample	no sample	58	70	no sample	49	outlier	154	outlier	64	80.33333	38.27619
1 Water	no sample	1259	66	2695.121	1820	1175	1425	no sample	1453.8	561.9	178	no sample	no sample	1181.536	627.1544
2 Water	no sample	312	172	74	outlier	305	88	no sample	70	29	60	no sample	no sample	138.75	112.4414
3 Water	no sample	no sample	outlier	29	96	15	30	no sample	20	58	122	no sample	no sample	52.85714	41.37805
4 Water	no sample	396	161	450	327.58	164	outlier	no sample	36	40	90	no sample	no sample	208.0725	162.1658
5 Water	no sample	196	200	30	544	77	66	no sample	441.9	744.44	260	no sample	no sample	284.3711	243.6189
6 Water	no sample	58	148	203	outlier	234	190	no sample	264	238.96	188	no sample	no sample	190.4955	64.55133
7 Water	no sample	407	73	15	765.63	64	305	no sample	outlier	420.75	100	no sample	no sample	258.7975	257.3289
8 Water	no sample	1652	88	outlier	990	378	130	no sample	770	187.91	200	no sample	no sample	549.4888	551.5484
9 Water	no sample	371	22	32	no sample	500	78	no sample	251.1	273.91	200	no sample	no sample	216.0013	169.0556
I Water	no sample	145	90	31	94.62	36	38	25	1	27	34	32	no sample	50.32909	41.7741
II Water	no sample	38	outlier	9	22	26	6	39	3	27	outlier	14	no sample	20.44444	13.29578
III Water	no sample	38	49	9	10	81	8	12	2	24	94	25	no sample	32	30.93865
IV Water	no sample	45	113	25	34	100	35	48	7	31	outlier	23	no sample	46.1	33.97859
V Water	no sample	38	outlier	9	27	23	15	16	1	20	outlier	32	no sample	20.11111	11.45038
VI Water	no sample	52	outlier	3	8	28	24	7	0	29	outlier	17	no sample	18.66667	16.50757
VII Water	no sample	46	86	48	63.22	84	38	25	2	31	32	28	no sample	43.92909	25.46243
VIII Water	no sample	71	outlier	24	outlier	47	34	26	2	29	62	26	no sample	35.66667	21.13646
IX Water	no sample	outlier	32	20	36	outlier	26	16	1	15	32	20	no sample	22	10.87428
I Water	no sample	31	37	20	no sample	52	16	no sample	1	9	40	outlier	no sample	25.75	17.18596
II Water	no sample	180	62	27	no sample	outlier	61	no sample	40	144	40	39	no sample	74.125	56.30894
III Water	no sample	42	37	21	no sample	48	44	no sample	10	18	no sample	50	no sample	33.75	15.23858
IV Water	no sample	outlier	73	22	no sample	outlier	22	no sample	5	18	no sample	66	no sample	34.33333	28.03331
V Water	no sample	54	93	31	no sample	outlier	38	no sample	1	20	52	116	no sample	50.625	37.84909
VI Water	no sample	116	57	64	no sample	125	168	no sample	32	44	66	outlier	no sample	84	47.08351
VII Water	no sample	72	43	27	no sample	outlier	30	no sample	5	16	56	outlier	no sample	35.57143	23.17223
VIII Water	no sample	130	152	31	no sample	132	364	no sample	outlier	506	40	814	no sample	271.125	273.3514

Table B-8 Sample TSS Concentrations (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std Dev
Lagoon	405	490	1300	1780	2820	2085.71	1480.1183	940.2776
Exercise runoff	5	3	122	80.8	37	64	51.966667	46.27836
Facultative Pond	83.33	16	32	170.2	196	187.93	114.24333	80.7668
Cell 1 Influent	outlier	13	34.545	124	188	1017.65	275.439	420.8208
Cell 2 Influent	outlier	20	21	22	31	136.76	46.152	50.84108
Cell 3 Influent	535	0	7	18	604	1493.75	442.95833	584.0258
Cell 3 effluent	139	2	6	no sample	6	230.43	76.686	103.7922
Filter Strip Runoff	1380	0	8	no sample	22	dry	352.5	685.0603
1 _{in}	no sample	14	26	dry	tracer	55	31.666667	21.07922
2 _{in}	no sample	1	33	dry	tracer	98	44	49.42671
3 _{in}	no sample	dry	dry	dry	tracer	2637.5	2637.5	#DIV/0!
4 _{in}	no sample	dry	26	dry	tracer	tracer	26	#DIV/0!
5 _{in}	no sample	16	16	17	tracer	tracer	16.333333	0.57735
6 _{in}	no sample	28	24	8	tracer	tracer	20	10.58301
7 _{in}	no sample	23	50	18	tracer	tracer	30.333333	17.21434
8 _{in}	no sample	23	36	7	tracer	tracer	22	14.52584
9 _{in}	no sample	1	14	17	tracer	tracer	10.666667	8.504901
1 _{out}	no sample	3	tracer	5	23	29	15	12.96148
II _{out}	no sample	2	tracer	30	48	61	35.25	25.55223
III _{out}	no sample	5	tracer	34	22	82	35.75	33.04921
IV _{out}	no sample	2	tracer	4	24	32	15.5	14.82116
V _{out}	no sample	588	tracer	8	dry	128.79	241.59667	306.0131
VI _{out}	no sample	1	tracer	12	16	30	14.75	11.98263
VII _{out}	no sample	1	tracer	20	3	25	12.25	12.03813
VIII _{out}	no sample	dry	tracer	37	27	25	29.666667	6.429101

Table B-9 Sample TP Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std Dev
Lagoon	121.561	no sample	75.009	120.974	110.716	115.994	88.461	96.559	451.029	79.5283	outlier	31.1136	0.5277	116.9912	123.3665
Exercise runoff	13.125	16.09	65.396	17.751	20.205	18.652	no sample	no sample	no sample	no sample	no sample	no sample	no sample	27.6188	21.17057
Facultative Pond	16.731	25.88	26.921	24.122	22.367	19.021	24.072	31.962	38.904	38.2547	42.4551	11.7366	0.127	25.4852	11.91903
Cell 1 Influent	15.829	15.48	11.531	11.255	17.64	19.695	25.582	no sample	33.697	32.9481	38.0724	10.1423	0.2133	19.47783	11.42244
Cell 2 Influent	20.337	18.54	8.808	13.629	16.82	21.789	28.35	no sample	34.193	34.1274	32.5543	20.6892	1.4507	20.97733	10.70051
Cell 3 Influent	16.216	15.36	10.584	11.63	13.716	14.561	21.052	19.649	18.691	20.9764	24.1764	20.4459	0.8434	15.97401	6.348454
Cell 3 Effluent	12.481	13.64	12.123	6.758	no sample	10.808	18.2836	no sample	17.451	18.1368	20.0302	11.9868	0.9527	13.01701	5.91275
Filter Strip Runoff	9.647	no sample	11.531	no sample	no sample	11.639	18.2836	no sample	15.715	20.9764	17.8942	13.5811	0.637	13.78216	6.29967
1 Water	no sample	12.596	9.046	15.003	14.488	18.098	28.17	no sample	23.333	28.2311	29.7902	no sample	no sample	19.8817	7.706035
1 Sediment	no sample	no sample	no sample	no sample	no sample	7.783	0.78	1.9	3.571	7.0613	no eval	no sample	no sample	4.21506	3.092851
2 Water	no sample	43.25	7.287	14.878	17.084	20.712	27.512	no sample	26.63	29.4104	34.1877	no sample	no sample	24.55012	10.8474
2 Sediment	no sample	no sample	no sample	no sample	no sample	5.450	no sample	1.1	2.207	0.0938	0.239	no sample	no sample	1.81912	2.200493
3 Water	no sample	no sample	16.585	12.754	16.587	12.992	26.853	no sample	26.506	28.2311	32.3031	no sample	no sample	21.6014	7.679476
3 Sediment	no sample	no sample	no sample	no sample	no sample	10.901	1.109	1.844	5.43	3.7594	7.9684	no sample	no sample	5.1353	3.785488
4 Water	no sample	26.49	9.675	28.869	17.115	13.844	27.018	no sample	26.258	38.8443	33.5595	no sample	no sample	24.59031	9.459852
4 Sediment	no sample	no sample	no sample	no sample	no sample	8.809	14.311	no sample	4.314	1.8728	no eval	no sample	no sample	7.32665	5.471174
5 Water	no sample	32.24	12.065	8.881	22.676	21.02	31.125	no sample	30.226	38.2547	51.7779	no sample	no sample	27.58507	13.22035
5 Sediment	no sample	no sample	no sample	no sample	no sample	12.992	no sample	5.578	11.629	16.4387	no eval	no sample	no sample	11.65943	4.531441
6 Water	no sample	46.56	8.167	16.377	20.297	15.637	29.816	no sample	26.506	42.9717	35.4442	no sample	no sample	26.86399	13.03159
6 Sediment	no sample	no sample	no sample	no sample	no sample	3.58	no eval	0.461	2.703	0.4946	0.2566	no sample	no sample	1.49904	1.533786
7 Water	no sample	30.77	14.7	9.506	19.061	20.712	34.425	no sample	35.805	33.5377	34.1877	no sample	no sample	25.85604	9.933498
7 Sediment	no sample	no sample	no sample	no sample	no sample	6.102	4.599	1.676	4.314	14.3726	1.7364	no sample	no sample	5.466667	4.692224
8 Water	no sample	23.92	10.805	32.367	13.901	20.521	32.121	no sample	27.746	39.4339	49.265	no sample	no sample	27.78666	12.17412
8 Sediment	no sample	no sample	no sample	no sample	no sample	12.408	17.669	31.323	14.107	11.7217	19.1104	no sample	no sample	17.72318	7.269499
9 Water	no sample	17.44	10.679	13.878	no sample	no eval	23.726	no sample	25.866	42.3821	38.5852	no sample	no sample	24.65376	12.07068
9 Sediment	no sample	no sample	no sample	no sample	no sample	17.913	no eval	17.731	30.102	22.9245	no eval	no sample	no sample	22.16763	5.811272
I Water	no sample	6.79	13.444	11.255	9.915	18.16	outlier	18.53	22.539	20.2123	23.131	17.8685	no sample	15.98448	5.499172
I Sediment	no sample	no sample	no sample	no sample	no sample	4.995	no eval	no eval	no eval	4.217	no eval	no eval	no sample	4.606	0.550129
II Water	no sample	9.24	17.716	10.006	11.955	9.393	17.701	18.451	15.348	16.4387	19.7387	17.0101	no sample	14.63614	3.779364
II Sediment	no sample	no sample	no sample	no sample	no sample	6.81	7.694	1.196	1.706	14.0189	no eval	no sample	no sample	6.28498	5.218699
III Water	no sample	8.75	4.021	7.382	12.047	4.472	16.154	15.908	17.826	16.4387	23.508	18.2364	no sample	13.15865	6.284754
III Sediment	no sample	no sample	no sample	no sample	no sample	14.838	12.961	12.294	17.699	10.2453	11.989	9.4888	no sample	12.78784	2.7864
IV Water	no sample	9.12	7.413	9.131	8.825	14.868	20.269	17.89	22.787	18.7972	24.1362	15.1705	no sample	15.1279	6.228323
V Water	no sample	12.17	14.7	10.006	11.955	10.562	17.043	18.53	21.175	16.6745	24.1362	19.2176	no sample	16.01539	4.577043
VI Water	no sample	8.14	16.459	12.004	13.407	8.378	15.134	15.972	15.1	18.0896	outlier	18.6044	no sample	14.1288	3.658673
VII Water	no sample	9.36	12.313	10.131	4.354	14.922	21.52	17.411	22.167	22.3349	24.7644	17.0101	no sample	15.99613	6.466835
VII Sediment	no sample	no sample	no sample	no sample	no sample	9.393	no eval	no eval	no eval	21.6839	1.6862	no sample	no sample	10.92103	10.08604
VIII Water	no sample	9.12	20.983	8.382	13.098	10.039	19.446	17.731	19.688	21.7453	25.3926	17.6233	no sample	16.65893	5.671991
VIII Sediment	no sample	no sample	no sample	no sample	no sample	6.336	5.784	4.362	2.847	10.7241	1.4712	no sample	no sample	5.25405	3.233342
IX Water	no sample	6.18	12.187	7.008	15.508	9.824	19.282	17.731	19.068	19.033	27.2773	20.076	no sample	15.74312	6.369125
IX Sediment	no sample	no sample	no sample	no sample	no sample	4.472	4.5	5.801	4.188	4.7028	6.7622	no sample	no sample	5.070667	0.999669
x Water	no sample	4.1	11.308	6.133	no sample	12.562	21.271	no sample	18.443	19.6792	no eval	19.8357	no sample	14.16649	6.63227
x Sediment	no sample	no sample	no sample	no sample	no sample	5.18	no eval	10.247	28.738	93.0896	no sample	12.6	no sample	29.97092	36.36915
xi Water	no sample	9.48	8.418	7.882	no sample	12.608	19.01	no sample	18.939	19.7972	23.1713	17.5055	no sample	15.22344	5.662058
xi Sediment	no sample	no sample	no sample	no sample	no sample	11.22	15.331	20.809	17.203	12.9575	no sample	15.298	no sample	15.43642	3.281155
xii Water	no sample	9.6	9.925	7.507	no sample	12.069	20.632	no sample	18.691	18.6179	no sample	19.8357	no sample	14.6097	5.348549
xii Sediment	no sample	no sample	no sample	no sample	no sample	no eval	2.788	1.004	1.954	no sample	no sample	1.3944	no sample	1.7851	0.773972
xiii Water	no sample	8.99	12.313	4.509	no sample	11.793	23.825	no sample	17.327	18.0283	no sample	14.3169	no sample	13.88778	5.936839
xiii Sediment	no sample	no sample	no sample	no sample	no sample	3.332	no eval	5.354	7.409	9.8915	no sample	2.1758	no sample	5.63242	3.107051
xiv Water	no sample	8.5	11.811	8.007	no sample	10.101	18.557	no sample	15.219	18.0283	no eval	17.3829	no sample	13.45078	4.369888
xiv Sediment	no sample	no sample	no sample	no sample	no sample	6.594	no eval	13.221	12.938	2.1085	no sample	6.836	no sample	6.3395	4.719849
xv Water	no sample	7.4	7.79	5.259	no sample	14.007	22.197	no sample	17.575	20.9764	no eval	18.9772	no sample	14.2727	6.689209
xv Sediment	no sample	no sample	no sample	no sample	no sample	0.103	1.417	1.612	6.814	12.7689	no sample	3.0341	no sample	4.2915	4.749661
xvi Water	no sample	5.81	10.805	7.507	no sample	13.3	20.92	no sample	15.467	16.2594	no eval	17.0149	no sample	13.38541	5.08702
xvi Sediment	no sample	no sample	no sample	no sample	no sample	2.258	no eval	1.036	8.649	11.0708	no sample	5.4623	no sample	5.89522	4.218967
xvii Water	no sample	6.67	18.218	12.879	no sample	13.269	18.397	no sample	19.931	17.4387	no eval	17.2602	no sample	15.50786	4.343898
xvii Sediment	no sample	no sample	no sample	no sample	no sample	0.627	3.544	2.188	4.259	0.942	no sample	2.5435	no sample	2.350583	1.420187

Table B-10 Sample TP Concentrations (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std Dev
Lagoon	71.59	71.95	50.978	69.731	64.79	55.719	67.459667	12.26549
Exercise runoff	9.28	6.37	24.043	18.083	12.98	10.78	13.922667	6.047825
Facultative Pond	12.19	12.71	13.123	16.848	15.52	10.89	13.546833	2.216789
Cell 1 Influent	26.89	16.19	13.24	16.151	15.11	12.865	16.741	5.169032
Cell 2 Influent	9.25	11.54	13.709	10.812	12.89	10.092	11.382167	1.688098
Cell 3 Influent	9.16	9.22	11.484	12.437	13.37	12.918	11.4315	1.845627
Cell 3 Effluent	9.39	16.19	8.907	no sample	12.17	8.467	11.0248	3.228419
Filter Strip Runoff	10.42	17.35	10.429	no sample	8.34	dry	11.63475	3.934841
1 _w	no sample	6.32	14.06	dry	tracer	14.753	11.711	4.681583
2 _w	no sample	15.03	14.294	dry	tracer	13.176	14.166667	0.933536
3 _w	no sample	dry	dry	dry	tracer	21.757	21.757	#DIV/0!
4 _w	no sample	dry	13.24	dry	tracer	13.24	13.24	#DIV/0!
5 _w	no sample	25.48	17.456	14.759	tracer	19.231867	5.576711	
6 _w	no sample	8.36	15.114	13.25	tracer	12.241333	3.488149	
7 _w	no sample	22	16.519	14.178	tracer	17.565667	4.014667	
8 _w	no sample	12.71	13.123	11.741	tracer	12.524667	0.709396	
9 _w	no sample	30.15	17.691	18.937	tracer	22.259333	6.861658	
1 _s	no sample	8.81	tracer	6.634	9.78	8.61	8.4585	1.319301
2 _s	no sample	10.67	tracer	10.812	11.69	8.514	10.4215	1.349307
3 _s	no sample	19.04	tracer	12.786	16.48	10.618	14.731	3.756163
4 _s	no sample	16.72	tracer	7.795	11.93	12.387	12.208	3.648837
5 _s	no sample	20.19	tracer	9.536	dry	13.178	14.300667	5.41531
6 _s	no sample	10.44	tracer	5.706	12.85	8.204	9.25	2.979382
7 _s	no sample	12.3	tracer	8.143	11.45	9.375	10.317	1.899966
8 _s	no sample	dry	tracer	8.491	12.41	9.136	10.012333	2.101335

Table B-11 Sample Ammonia Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std. Dev
Lagoon	170.698	no sample	239.54	441.35	511.97	outlier	292.56	288.77	475	437	396.23	249.11	250.15	358.168	104.691
Exercise runoff	5.874	31.92	16.24	9.32	7.32	14.49	no sample	no sample	no sample	no sample	no sample	no sample	no sample	15.858	9.690821
Facultative Pond	16.348	17.26	4.66	5.37	11.01	7.26	4.78	22.58	46.4	93.4	outlier	85.01	50.49	31.65636	32.68665
Cell 1 Influent	4.547	2.14	2.92	4.24	12.45	8.54	12.83	no sample	no sample	outlier	outlier	10	5.81	7.36826	4.19676
Cell 2 Influent	10.671	7.61	7.16	2.01	1.37	15.09	21.9	no sample	34.8	outlier	0.77	25.64	19.49	13.584	11.67174
Cell 3 Influent	1.438	0.4	0.59	0.64	1.12	3.22	10.02	10.97	23.4	38.3	31.25	24.57	18.67	13.59583	13.34299
Cell 3 effluent	0.178	0.49	0.29	0.51	no sample	0.95	3.17	no sample	9.2	outlier	10.65	14.08	8.21	5.283333	5.291812
Filter Strip Runoff	0.194	no sample	0.27	no sample	no sample	1.37	3.73	no sample	7.2	19.8	0.55	17.45	7.21	7.1975	7.579104
1 Water	no sample	14.06	10.94	16.82	12.45	5.71	12.31	no sample	26.9	28.5	outlier	no sample	no sample	15.96125	7.902895
1 Sediment	no sample	no sample	no sample	no sample	no sample	39.99	24.75	37.59	45.6	38.7	73.92	no sample	no sample	43.425	16.44143
2 Water	no sample	11	11.39	20.48	14.07	no eval	16.42	no sample	25.7	outlier	outlier	no sample	no sample	18.51	5.705317
2 Sediment	no sample	no sample	no sample	no sample	no sample	55.35	no sample	33.09	54	57	67.82	no sample	no sample	53.452	12.62479
3 Water	no sample	no sample	12.84	26.97	17.98	14.49	15.76	no sample	42.7	41.2	outlier	no sample	no sample	24.56286	12.72306
3 Sediment	no sample	no sample	no sample	no sample	no sample	55.35	26.04	19.88	47.1	60.2	42.24	no sample	no sample	42.135	15.61792
4 Water	no sample	20.34	13.36	39.99	28.18	16.36	14.51	no sample	43.1	51.7	57.09	no sample	no sample	31.62556	16.77757
4 Sediment	no sample	no sample	no sample	no sample	no sample	28.9	20.17	no sample	no eval	58.2	38.75	no sample	no sample	36.505	16.33282
5 Water	no sample	16.57	11.36	26.97	23.93	21.75	17.83	no sample	39.8	outlier	outlier	no sample	no sample	22.60143	9.154959
5 Sediment	no sample	no sample	no sample	no sample	no sample	12.31	no sample	14.15	46	69	59.6	no sample	no sample	40.212	25.961
6 Water	no sample	8.26	10.51	19.69	14.66	12.82	20.17	no sample	40.4	73.2	73.92	no sample	no sample	30.40333	26.9108
6 Sediment	no sample	no sample	no sample	no sample	no sample	35.41	no eval	44.55	49.2	65.1	48.06	no sample	no sample	48.484	10.7809
7 Water	no sample	7.92	9.33	11.8	21.17	17.75	19.36	no sample	44	66.4	87.81	no sample	no sample	31.72667	28.33589
7 Sediment	no sample	no sample	no sample	no sample	no sample	51.03	33.05	40.92	58.5	57.9	59.6	no sample	no sample	50.16667	10.93127
8 Water	no sample	12.96	13.36	22.15	10.57	10.9	19.36	no sample	49.1	72.5	91.68	no sample	no sample	33.62	30.29431
8 Sediment	no sample	no sample	no sample	no sample	no sample	32.64	34.44	62.58	47.7	59	80.57	no sample	no sample	52.62167	18.30182
9 Water	no sample	14.06	8.27	15.55	no sample	9.27	10.02	no sample	39.1	outlier	44.1	no sample	no sample	20.05266	15.01673
9 Sediment	no sample	no sample	no sample	no sample	no sample	30.1	20.17	21.64	40.8	49	46.04	no sample	no sample	34.625	12.43468
I Water	no sample	0.4	10.51	6.54	1.32	2.24	2.69	10.07	31.9	48.5	40.46	31.76	no sample	16.94455	17.68069
I Sediment	no sample	no sample	no sample	no sample	no sample	21.75	11.34	6.59	no eval	no eval	no eval	11.87	no sample	12.8875	6.367429
II Water	no sample	0.35	44.28	6.04	0.56	1.22	2.28	3.79	18.5	33.2	42.24	33.15	no sample	16.87545	17.92693
II Sediment	no sample	no sample	no sample	no sample	no sample	27.5	15.76	16.07	21.6	35.4	15.69	no sample	no sample	22.00333	8.04846
III Water	no sample	0.37	4.92	2.26	0.42	1.08	1.17	8.15	8.07	outlier	outlier	no sample	no sample	3.305	3.302073
III Sediment	no sample	no sample	no sample	no sample	no sample	20.88	12.83	16.77	25.2	35.8	42.24	31.76	no sample	26.49714	10.62012
IV Water	no sample	0.68	5.55	4.24	0.56	3.22	5.19	5.8	16.8	18.6	outlier	outlier	no sample	6.74	6.518004
V Water	no sample	0.51	12.84	3.92	0.42	1.68	2.69	7.81	18.5	19.8	40.46	42.86	no sample	13.77182	15.40685
VI Water	no sample	0.29	15.06	4.59	0.37	1.37	2.69	2.94	17.1	14.2	42.24	39.34	no sample	12.74455	15.18254
VII Water	no sample	0.43	1.49	4.08	0.54	2.85	7.51	9.65	12.8	15.6	outlier	outlier	no sample	6.105556	5.57548
VII Sediment	no sample	no sample	no sample	no sample	no sample	27.75	no eval	27.92	21.8	38.7	27.46	no sample	no sample	28.726	6.137082
VIII Water	no sample	0.41	51.96	4.24	0.95	1.55	4.22	8.15	12.9	16.3	38.75	41.06	no sample	16.40818	18.61074
VIII Sediment	no sample	no sample	no sample	no sample	no sample	21.75	13.37	29.13	19.8	34.2	26.31	no sample	no sample	24.09333	7.366684
IX Water	no sample	0.26	4.37	3.09	3.24	0.61	5.87	2.94	10.2	17.3	54.89	53.09	no sample	14.15091	20.23074
IX Sediment	no sample	no sample	no sample	no sample	no sample	32.64	20.17	44.55	39.8	31	24.13	no sample	no sample	32.04833	9.182852
i Water	no sample	2.42	0.78	2.64	no sample	1.9	2.92	no sample	17.8	16.5	21.21	22.55	no sample	9.857778	9.34375
i Sediment	no sample	no sample	no sample	no sample	no sample	2.9	2.47	5.56	7.78	15.1	no sample	9.18	no sample	7.165	4.694932
ii Water	no sample	2.96	3.87	5.16	no sample	2.85	7.51	no sample	21.4	17.1	38.75	31.76	no sample	14.59556	13.50113
ii Sediment	no sample	no sample	no sample	no sample	no sample	1.7	1.57	5.11	12.1	17.1	no sample	8.07	no sample	7.608333	6.133376
iii Water	no sample	0.53	1.96	7.65	no sample	2.63	10.88	no sample	34.2	20.2	no sample	41.06	no sample	14.88875	15.48336
iii Sediment	no sample	no sample	no sample	no sample	no sample	2.46	1.71	7.81	14.2	10.5	no sample	20.7	no sample	9.563333	7.233363
iv Water	no sample	1.02	2.04	4.77	no sample	1.75	8.5	no sample	15.2	14.5	no sample	27.94	no sample	9.465	9.323635
iv Sediment	no sample	no sample	no sample	no sample	no sample	1.77	0.92	0.97	11	7.73	no sample	7.1	no sample	4.915	4.26942
v Water	no sample	1.6	2.13	7.96	no sample	1.83	7.51	no sample	10.4	10.4	no eval	outlier	no sample	5.975714	4.01172
v Sediment	no sample	no sample	no sample	no sample	no sample	1.55	no eval	4.49	8.4	7.21	no sample	11.37	no sample	6.604	3.752317
vi Water	no sample	0.55	0.88	1.65	no sample	1.75	6.12	no sample	8.93	16.5	no eval	25.64	no sample	7.7525	9.048789
vi Sediment	no sample	no sample	no sample	no sample	no sample	0.91	1	5.33	9.5	6.22	no sample	5.26	no sample	4.703333	3.289831
vii Water	no sample	0.37	1.08	2.54	no sample	1.55	4.8	no sample	8	15.2	no eval	20.7	no sample	6.78	7.454435
vii Sediment	no sample	no sample	no sample	no sample	no sample	1.22	0.5	0.79	9.65	7.3	no sample	5.26	no sample	4.12	3.862543
viii Water	no sample	0.45	3.05	6.04	no sample	3.36	7.83	no sample	7.24	9.75	no eval	outlier	no sample	5.388571	3.235436
viii Sediment	no sample	no sample	no sample	no sample	no sample	1.03	1.45	3.48	7.38	7.49	no sample	8.43	no sample	4.876667	3.292778

Table B-12 Sample Ammonia Concentrations (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std. Dev
Lagoon	213.6	334.488	442.65	348.16	962.79	464.42	461.018	261.567
Exercise runoff	1.88	14.214	34.59	48.37	7.81	8.46	19.220667	18.20802
Facultative Pond	8.61	31.002	64.75	36.692	27.86	45.8	35.452333	19.37159
Cell 1 Influent	0.94	21.827	13.8	16.666	22.2	4.7	13.3555	8.834147
Cell 2 Influent	<0.5	19.417	9.47	1.756	12.3	9.16	10.4206	6.364656
Cell 3 Influent	<0.5	14.779	13.8	1.623	1.67	3.86	7.1464	6.59216
Cell 3 effluent	<0.5	5.797	1.124	no sample	0.49	1.02	2.10775	2.475119
Filter Strip Runoff	<0.5	5.157	0.65	no sample	0.34	dry	2.049	2.696066
1 _w	no sample	29.817	29.27	dry	tracer	3.71	20.932333	14.91749
2 _w	no sample	40.732	19.27	dry	tracer	24.44	28.147333	11.20101
3 _w	no sample	dry	dry	dry	tracer	20.88	20.88	#DIV/0!
4 _w	no sample	dry	14.38	dry	tracer	14.38	14.38	#DIV/0!
5 _w	no sample	45.786	14.38	27.833	tracer	tracer	29.333	15.75664
6 _w	no sample	26.525	12.17	12.149	tracer	tracer	16.948	8.293932
7 _w	no sample	4.588	15.64	24.725	tracer	tracer	14.984333	10.0845
8 _w	no sample	10.819	14.38	8.516	tracer	tracer	11.238333	2.954404
9 _w	no sample	14.779	21.84	18.029	tracer	tracer	18.216	3.534212
1 _w	no sample	2.764	tracer	0.766	0.51	7.83	2.9675	3.394664
ii _w	no sample	5.797	tracer	4.9	1.32	1.5	3.37925	2.304364
iii _w	no sample	9.624	tracer	9.587	5.68	2.61	6.87525	3.392649
iv _w	no sample	3.925	tracer	2.056	1.99	5.72	3.42275	1.774861
v _w	no sample	2.658	tracer	1.826	dry	3.16	2.548	0.673769
vi _w	no sample	3.359	tracer	1.137	1.39	2.32	2.0515	1.009214
vii _w	no sample	7.617	tracer	0.797	0.56	0.77	2.436	3.455624
viii _w	no sample	dry	tracer	0.737	0.45	6.43	2.539	3.372759

Table B-13 Sample Nitrate Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jul-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std. Dev.
Lagoon	2.72	no sample	outlier	1.452	2.49	2.53	4.29	12.69	3.59	8.92	5.86	17.81	outlier	6.625778	5.511707
Exercise runoff	0.71	0.99	0.65	7.501	1.02	1.06	no eval	no sample	no sample	no sample	no sample	no sample	no sample	2.2442	2.943188
Facultative Pond	0.94	0.82	1.09	2.214	1.16	1.12	1.17	1.37	0.181	0.464	3.14	3.39	outlier	1.463545	1.031474
Cell 1 influent	0.68	0.78	0.45	1.878	1.46	1.34	1.43	no sample	0.209	0.701	0.673	outlier	1.98	1.0901	0.608743
Cell 2 influent	0.62	0.68	0.48	1.878	1.46	1.19	1.32	no sample	1.05	0.739	1.55	1.86	2.74	1.360636	0.651019
Cell 3 influent	0.75	0.75	0.41	1.505	1.27	0.84	1.43	1.69	0.568	0.345	0.126	outlier	outlier	0.8934	0.54681
Cell 3 effluent	0.71	0.9	0.43	2.925	no sample	0.89	1.43	no sample	0.209	0.412	0.117	1.71	outlier	1.002556	0.90088
Filter Strip Runoff	no sample	no sample	0.88	no sample	no sample	1	1.37	no sample	0.39	0.537	0.03	2.08	3.6	1.260875	1.203603
1 Water	no sample	0.71	0.98	outlier	1.52	1.51	1.32	no sample	0.042	0.873	0.34	no sample	no sample	0.911875	0.537822
1 Sediment	no sample	no sample	no sample	no sample	no sample	1.82	no eval	3.31	0.94	2.21	2.53	no sample	no sample	2.162	0.875483
2 Water	no sample	0.86	0.53	3.092	1.9	no eval	1.37	no sample	0.047	0.635	0.522	no sample	no sample	1.1195	0.979762
2 Sediment	no sample	no sample	no sample	no sample	no sample	0.72	no eval	4.26	0.993	2.15	1.27	no sample	no sample	1.8766	1.435423
3 Water	no sample	no sample	0.88	2.034	1.27	1	1.55	no sample	0.218	0.592	0.939	no sample	no sample	1.035375	0.575531
3 Sediment	no sample	no sample	no sample	no sample	no sample	1.56	2.71	3.91	0.914	2.74	4.72	no sample	no sample	2.759	1.415253
4 Water	no sample	1.36	1.33	outlier	0.89	1.6	1.21	no sample	0.334	1.26	0.47	no sample	no sample	1.05675	0.450554
4 Sediment	no sample	no sample	no sample	no sample	no sample	0.84	6.35	no sample	1.35	5.18	3.82	no sample	no sample	3.508	2.38459
5 Water	no sample	0.9	0.88	2.478	1.74	0.84	1.32	no sample	0.914	0.477	0.564	no sample	no sample	1.123667	0.634218
5 Sediment	no sample	no sample	no sample	no sample	no sample	0.75	no eval	2.47	0.449	16.2	1.73	no sample	no sample	4.3198	6.689442
6 Water	no sample	0.86	0.62	1.777	1.16	1.51	1.61	no sample	0.023	0.957	1.3	no sample	no sample	1.090778	0.547465
6 Sediment	no sample	no sample	no sample	no sample	no sample	0.78	10.49	10.29	3.01	7.87	6.62	no sample	no sample	6.51	3.926153
7 Water	no sample	0.9	0.65	outlier	1.11	1.42	1.43	no sample	1	0.635	0	no sample	no sample	0.893125	0.47022
7 Sediment	no sample	no sample	no sample	no sample	no sample	0.75	2.62	4.26	1.31	4.88	4.16	no sample	no sample	2.996667	1.704731
8 Water	no sample	0.71	1.09	2.098	1.33	1.7	1.49	no sample	1.12	0.89	0	no sample	no sample	1.158667	0.60588
8 Sediment	no sample	no sample	no sample	no sample	no sample	1.17	3	outlier	1.07	3.15	2.13	no sample	no sample	2.104	0.979684
9 Water	no sample	0.94	0.68	outlier	no sample	1.42	1.32	no sample	0.375	0.865	0.717	no sample	no sample	0.902429	0.36675
9 Sediment	no sample	no sample	no sample	no sample	no sample	0.78	2.81	13.8	0.675	1.33	1.8	no sample	no sample	3.5325	5.089545
10 Water	no sample	0.75	0.5	1.847	outlier	1.51	2.74	1.31	1.13	0.65	0.74	2.79	no sample	1.3967	0.833407
10 Sediment	no sample	no sample	no sample	no sample	no sample	6.99	no eval	25.96	17.5	19.7	21.9	9.92	no sample	16.995	7.240966
11 Water	no sample	0.82	0.62	6.454	outlier	4.47	2.63	4.44	0.469	0.339	0.226	2.41	no sample	2.2878	2.190284
11 Sediment	no sample	no sample	no sample	no sample	no sample	2.97	1.41	9.46	5.78	8.32	12.3	no sample	no sample	6.706667	4.107192
12 Water	no sample	0.78	0.23	outlier	no sample	no eval	1.55	2.8	0.894	0.451	0.975	2.29	no sample	1.24625	0.90048
12 Sediment	no sample	no sample	no sample	no sample	no sample	no eval	1.84	2.36	0.422	1.87	1.27	2.79	no sample	1.758667	0.833035
13 Water	no sample	0.82	0.5	1.677	1.46	1.12	1.61	outlier	0.191	0.571	0.751	outlier	no sample	0.966667	0.527891
13 Sediment	no sample	0.99	0.65	outlier	outlier	5.7	5.05	3.6	0.385	0.477	1.18	2.53	no sample	2.284667	2.047768
14 Water	no sample	0.9	0.56	16.896	17.8	6.99	8.99	5.71	11.3	0.497	0.245	2.29	no sample	6.379818	8.475191
14 Sediment	no sample	0.94	0.62	1.677	1.33	0.95	1.68	outlier	0.487	0.457	1.41	2.93	no sample	1.2481	0.748519
15 Water	no sample	no sample	no sample	no sample	no sample	1.43	no eval	19.31	12.8	7.4	4.7	no sample	no sample	9.128	7.053529
15 Sediment	no sample	0.99	0.84	6.151	outlier	5.26	1.37	4.26	1.03	0.47	0.05	2.41	no sample	2.2831	2.164859
16 Water	no sample	no sample	no sample	no sample	no sample	1.37	1.61	1.31	0.509	1.33	1.15	no sample	no sample	1.213167	0.375484
16 Sediment	no sample	1.03	0.84	6.454	outlier	8.23	1.12	10.73	2.77	0.425	0.273	1.98	no sample	3.3852	3.7237
17 Water	no sample	no sample	no sample	no sample	no sample	1.07	2.74	3.6	0.505	2.18	1.37	no sample	no sample	1.910833	1.147965
18 Water	no sample	0.82	0.62	2.098	no sample	0.88	1.49	no sample	0.047	0.635	no eval	1.98	no sample	1.07125	0.71695
18 Sediment	no sample	no sample	no sample	no sample	no sample	1.03	4.48	2.47	0.523	1.5	no sample	3.08	no sample	2.177167	1.457801
19 Water	no sample	0.68	0.72	outlier	no sample	0.95	outlier	no sample	0.181	0.477	no eval	outlier	no sample	0.5978	0.296277
19 Sediment	no sample	no sample	no sample	no sample	no sample	1.98	0.8	1.76	0.358	1.04	no sample	2.53	no sample	1.411333	0.814554
20 Water	no sample	0.86	0.59	2.344	no sample	1.12	no sample	2.8	0.626	0.45	no sample	2.41	no sample	1.2	0.832558
20 Sediment	no sample	no sample	no sample	no sample	no sample	no eval	1.35	2.8	0.36	1.49	no sample	2.29	no sample	1.658	0.936597
21 Water	no sample	0.75	0.65	2.098	no sample	3.8	0.95	no sample	0.065	0.694	no sample	1.71	no sample	1.339625	1.182147
21 Sediment	no sample	no sample	no sample	no sample	no sample	2.33	5.56	2.47	0.33	1.12	no sample	2.08	no sample	1.213167	0.375484
22 Water	no sample	0.86	0.62	2.478	no sample	1.98	1.21	no sample	outlier	1.75	no eval	3.08	no sample	1.568286	0.685717
22 Sediment	no sample	no sample	no sample	no sample	no sample	1.32	3.17	0.431	1.26	no sample	2.93	no sample	no sample	1.8222	1.177556
23 Water	no sample	0.9	0.65	2.344	no sample	0.81	no eval	1.12	0.151	0.778	no eval	2.08	no sample	1.104125	0.740568
23 Sediment	no sample	0.9	0.72	2.619	no sample	1.26	1.35	5.48	1.66	0.957	no sample	2.18	no sample	2.147833	1.684353
24 Water	no sample	no sample	no sample	no sample	no sample	1.07	1.75	no sample	0.066	0.621	no eval	1.88	no sample	1.20325	0.822615
24 Sediment	no sample	no sample	no sample	no sample	no sample	0.95	no eval	14.39	0.523	1.1	no sample	2.79	no sample	3.9506	5.89928
25 Water	no sample	0.82	0.56	4.079	no sample	1.82	1.12	no sample	0.536	0.94	no eval	2.41	no sample	1.535625	1.213312
25 Sediment	no sample	no sample	no sample	no sample	no sample	0.91	0.64	2.57	0.363	0.94	no sample	2.18	no sample	1.267167	0.891751

Table B-14 Sample Nitrate Concentrations (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std. Dev.
Lagoon	5.82	11.07	1.22	1.835	4.7	7.3	5.32416667	3.6489018
Exercise runoff	1.73	0.97	1.07	outlier	0.56	1.95	1.256	0.5716467
Facultative Pond	1.25	0.73	0.83	0.55	0.41	1.55	0.88666667	0.4336665
Cell 1 influent	1.11	0.97	0.94	0.821	0.43	1.88	1.02516667	0.4783599
Cell 2 influent	1.66	1.09	0.9	0.789	0.4	1.61	1.07483333	0.4892281
Cell 3 influent	1.53	1.13	0.79	0.758	0.4	1.81	1.06966667	0.5267719
Cell 3 effluent	1.6	1.09	0.9	no sample	0.43	1.61	1.126	0.4989289
Filter Strip Runoff	2.3	0.89	1.03	no sample	0.4	dry	1.155	0.8097119
1 _w	no sample	0.93	0.79	dry	tracer	outlier	0.86	0.0989949
2 _w	no sample	0.73	0.64	dry	tracer	1.23	0.86666667	0.3178574
3 _w	no sample	dry	dry	dry	tracer	0.97	0.97	#DIV/0!
4 _w	no sample	dry	dry	dry	tracer	0.67	0.67	#DIV/0!
5 _w	no sample	outlier	0.73	0.645	tracer	tracer	0.6875	0.0601041
6 _w	no sample	0.73	0.67	0.728	tracer	tracer	0.70933333	0.0340783
7 _w	no sample	1.38	0.61	0.699	tracer	tracer	0.89633333	0.4212248
8 _w	no sample	outlier	0.7	0.699	tracer	tracer	0.6995	0.0007071
9 _w	no sample	12.46	0.86	0.645	tracer	tracer	4.655	6.7601831
1 _{sw}	no sample	1.28	tracer	0.965	0.43	1.81	1.12125	0.5778751
2 _{sw}	no sample	1.49	tracer	1.088	0.38	1.61	1.142	0.5548838
3 _{sw}	no sample	17.05	tracer	1.133	0.52	2.37	5.26825	7.8920985
4 _{sw}	no sample	1.68	tracer	1.004	0.52	1.88	1.271	0.6254204
5 _{sw}	no sample	18.44	tracer	1.501	dry	3.11	7.68366667	9.3499332
6 _{sw}	no sample	1.33	tracer	0.855	0.38	1.38	0.98625	0.4683192
7 _{sw}	no sample	1.23	tracer	1.501	0.45	1.49	1.16775	0.494618
8 _{sw}	no sample	dry	tracer	1.627	0.74	1.27	1.21233333	0.446303

Table B-15 Sample TKN Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	26-Aug-03	9-Sep-03	23-Sep-03	7-Oct-03	21-Oct-03	4-Nov-03	Average	Std. Dev.
Lagoon	347.91	no sample	1749.85	707.23	876.42	571.2	547.33	743.12	1940.9	1350.38	1929.12	491.02	478.1	977.715	598.487
Exercise runoff	outlier	40.12	68.72	50.86	73.37	61.52	no sample	no sample	no sample	no sample	no sample	no sample	no sample	58.918	13.50931
Facultative Pond	192.03	45.02	60.63	50.48	115.94	62.22	8.06	123.28	outlier	outlier	outlier	130.41	97.57	88.564	53.53476
Cell 1 Influent	191.43	9.49	61.42	40.11	37.02	34.58	34.69	no sample	167.08	180.04	66.65	19.23	45.28	73.91833	65.72101
Cell 2 Influent	outlier	31.93	44.7	23.38	29.46	53.11	53.8	no sample	outlier	outlier	50.82	36.86	29.51	39.28556	11.56082
Cell 3 Influent	outlier	10.09	23.11	16.42	55.44	27.88	24.57	23.53	48.76	outlier	outlier	42.81	30.06	30.267	14.4016
Cell 3 Effluent	outlier	1.62	28.16	21.82	no sample	25.72	18.3	no sample	38.29	outlier	35.63	20.34	28.82	24.3	10.80307
Filter Strip Runoff	no sample	no sample	16	no sample	no sample	30.67	24.56	no sample	30.53	outlier	20.66	29.56	17.13	24.15857	6.331581
1 Water	no sample	22.18	43.21	53.63	35.28	44.24	37.6	no sample	70.74	47.22	71.93	no sample	no sample	47.33667	16.17023
1 Sediment	no sample	no sample	no sample	no sample	no sample	62.04	60.56	78.85	75.62	no eval	87.71	no sample	no sample	72.956	11.53621
2 Water	no sample	26.45	28.08	53.6	47.52	50.88	50.19	no sample	outlier	59.6	outlier	no sample	no sample	45.18857	12.81354
2 Sediment	no sample	no sample	no sample	no sample	no sample	71.58	no sample	78.62	64.53	no eval	72.15	no sample	no sample	71.72	5.759358
3 Water	no sample	no sample	46.36	43.96	42.65	36.42	50.49	no sample	77.37	64.63	outlier	no sample	no sample	51.69714	14.32598
3 Sediment	no sample	no sample	no sample	no sample	no sample	79.6	no eval	87.96	77.46	no eval	71.91	no sample	no sample	79.2325	6.659957
4 Water	no sample	35.84	27.43	106.89	37.72	48.08	44.06	no sample	67.11	64.81	90.32	no sample	no sample	58.02889	26.67811
4 Sediment	no sample	no sample	no sample	no sample	no sample	65.93	no eval	no sample	87.13	68.56	79.47	no sample	no sample	75.2725	9.841397
5 Water	no sample	35.57	23.47	18.95	66.85	64.32	60.56	no sample	74.34	86.48	outlier	no sample	no sample	54.0675	24.39384
5 Sediment	no sample	no sample	no sample	no sample	no sample	36.62	no sample	76.33	83.17	no eval	83.42	no sample	no sample	69.885	22.41864
6 Water	no sample	14.5	14.53	55.95	28.53	54.85	53.4	no sample	75.89	93.12	113.03	no sample	no sample	55.97778	33.96804
6 Sediment	no sample	no sample	no sample	no sample	no sample	80.19	no eval	79.63	no eval	no eval	71.92	no sample	no sample	77.24667	4.621519
7 Water	no sample	25.77	21.59	17.89	55.8	66.54	58.76	no sample	63.8	100.68	127.18	no sample	no sample	59.77889	36.51068
7 Sediment	no sample	no sample	no sample	no sample	no sample	70.29	92.46	79.2	no eval	125.42	81.64	no sample	no sample	89.802	21.42105
8 Water	no sample	44.41	96.38	99.28	36.48	56.77	61.89	no sample	73.35	95.36	134.86	no sample	no sample	77.64222	31.44043
8 Sediment	no sample	no sample	no sample	no sample	no sample	51.3	79.25	167.45	76.63	138.68	114.86	no sample	no sample	104.695	43.54909
9 Water	no sample	27.62	19	19.57	no sample	36.23	29.45	no sample	59.36	no eval	83.77	no sample	no sample	39.28571	23.89338
9 Sediment	no sample	no sample	no sample	no sample	no sample	51.87	no eval	56.33	60.15	99.34	89.37	no sample	no sample	71.412	21.43975
I Water	no sample	31.31	27.24	21.04	14.68	34.69	21.36	25.54	63.47	52.23	70.33	51.36	no sample	37.56818	18.72959
I Sediment	no sample	no sample	no sample	no sample	no sample	36.69	no eval	no eval	no eval	no eval	no eval	no eval	no sample	36.69	#DIV/0!
II Water	no sample	21.28	outlier	16.18	11.28	20.75	21.07	29.86	55.66	44.99	73.26	55.03	no sample	34.936	20.87055
II Sediment	no sample	no sample	no sample	no sample	no sample	37.39	32.61	no eval	no eval	no eval	no eval	no sample	no sample	35	3.37997
III Water	no sample	no value	19.81	17.86	12.08	33.75	no eval	56.05	42.71	25.29	74.36	48.14	no sample	36.67222	20.44791
III Sediment	no sample	no sample	no sample	no sample	no sample	32.48	28.16	28.69	51.3	89.37	63.17	34.66	no sample	46.83286	22.83378
IV Water	no sample	21.96	22.76	24.74	20.37	no eval	33.7	40.38	39.29	27.14	outlier	49.8	no sample	31.12667	10.21027
V Water	no sample	no value	29.93	11.84	15.8	18.87	23.61	44.45	37.11	30.69	70.5	56.45	no sample	33.925	18.68382
VI Water	no sample	35.57	32.99	26.56	13.98	0.78	56.47	14.77	27.86	27.94	73.26	52.71	no sample	32.99	20.95833
VII Water	no sample	17.2	9.52	20.51	14.1	24.3	17.62	34.49	26.82	28.89	outlier	42.98	no sample	23.843	10.04305
VII Sediment	no sample	no sample	no sample	no sample	no sample	44.26	no eval	no eval	no eval	no eval	43.83	no sample	no sample	44.045	0.304056
VIII Water	no sample	21.83	75	25.63	10.97	49.32	46.91	31.96	45.61	30.12	74.37	51.87	no sample	42.14455	20.50446
VIII Sediment	no sample	no sample	no sample	no sample	no sample	37.78	29	39.27	48.33	82.36	35.7	no sample	no sample	45.07333	19.10475
IX Water	no sample	26.74	12.73	8.47	24.46	28.21	25.92	24.12	43.27	28.47	outlier	73.28	no sample	29.567	17.97299
IX Sediment	no sample	no sample	no sample	no sample	no sample	54.37	48.61	60.56	56.05	67.76	54.31	no sample	no sample	56.94333	6.540329
X Water	no sample	16.36	15.8	4.07	no sample	26.81	13.26	no sample	35	33.47	no eval	45.24	no sample	23.75125	13.66634
X Sediment	no sample	no sample	no sample	no sample	no sample	14.92	no eval	22.82	30.46	41.47	no sample	24.08	no sample	26.75	9.911675
xi Water	no sample	25.53	15.43	19.64	no sample	10.35	33.85	no sample	42.25	32.35	outlier	47.58	no sample	28.3725	13.00545
xi Sediment	no sample	no sample	no sample	no sample	no sample	20.41	22.6	19.83	30.72	39.21	no sample	23.17	no sample	25.99	7.558674
xii Water	no sample	23.99	10.93	11.85	no sample	19.39	40.59	no sample	44.04	34.07	no sample	55.83	no sample	30.08625	16.1897
xii Sediment	no sample	no sample	no sample	no sample	no sample	16.02	20.57	35.17	26.59	36.55	no sample	35.03	no sample	28.32167	8.648987
xiii Water	no sample	15.13	35.48	27.93	no sample	27.32	26.09	no sample	41.34	28.58	no sample	44.42	no sample	30.78625	9.346547
xiii Sediment	no sample	no sample	no sample	no sample	no sample	17.02	no eval	19.37	29.88	29.05	no sample	20.26	no sample	23.116	5.922722
xiv Water	no sample	14.71	12.17	18.67	no sample	21.46	4.48	no sample	44.34	27.21	no eval	49.1	no sample	24.0175	15.56632
xiv Sediment	no sample	no sample	no sample	no sample	no sample	23.64	no eval	20.71	22.42	25.24	no sample	24.58	no sample	23.318	1.80267
xv Water	no sample	11.55	54.08	17.44	no sample	20.22	20.27	no sample	49.55	35.45	no eval	42.03	no sample	31.32375	16.08429
xv Sediment	no sample	no sample	no sample	no sample	no sample	38.56	16.75	11.06	22.36	17.87	no sample	14.53	no sample	20.18833	9.744478
xvi Water	no sample	27.07	13.07	25.11	no sample	28.95	28.77	no sample	24.95	31.13	no eval	42.38	no sample	27.67875	8.094756
xvi Sediment	no sample	no sample	no sample	no sample	no sample	14.5	no eval	no eval	20.33	15.2	no eval	14.03	no sample	16.015	2.916556
xvii Water	no sample	12.18	20.84	10.83	no sample	27.08	25.31	no sample	26.25	26.53	no eval	43.52	no sample	24.0675	10.18958
xvii Sediment	no sample	no sample	no sample	no sample	no sample	15.86	8.13	9.21	15.57	24.03	no sample	20.28	no sample	15.51333	6.158307

Table B-16 Sample BOD₅ Concentrations (2003)

Date	21-May-03	4-Jun-03	17-Jun-03	2-Jul-03	15-Jul-03	29-Jul-03	11-Aug-03	28-Aug-03	9-Sep-03	23-Sep-03	21-Oct-03	4-Nov-03	Average	Std. Dev
Lagoon	4370	no sample	>7920	178	633.5	554	710	1336	outlier	2670	2131	2440	1669.167	1354.364
Exercise runoff	no value	492.5	676	65	146	427.5	no sample	no sample	no sample	no sample	no sample	no sample	361.4	252.3785
Facultative Pond	36.4	100	329.5	no value	167.5	251	172.2	390	267.5	317	201	483	246.8273	129.7227
Cell 1 Influent	45	67.6	no eval	6.2	79.2	84.47	79.5	no sample	67	125.1	58.55	63.5	67.612	30.27065
Cell 2 Influent	59.45	55.9	71.3	33.2	53.1	144.1	115.2	no sample	109	outlier	55.9	67.2	79.435	35.04752
Cell 3 Influent	44.75	84.4	101.3	28.45	63.6	87.8	78.6	59.25	62.85	outlier	48.95	51.5	64.56818	21.28775
Cell 3 effluent	43.55	48.45	72	33.15	no sample	56.55	72.4	no sample	33	70.55	29.25	outlier	50.98889	17.64105
Filter Strip Runoff	56	no sample	no eval	no sample	no sample	96.8	59.4	no sample	45.6	118.2	51.75	38.4	66.56429	29.3925
1 Water	no sample	62.4	59.4	47.8	54.9	114	158.3	no sample	170	141.3	no sample	no sample	103.5125	49.01727
2 Water	no sample	60.6	69.6	23.4	outlier	39.7	102.5	no sample	42.75	56.8	no sample	no sample	56.47857	25.40151
3 Water	no sample	no sample	41.6	10	39.4	10.4	outlier	no sample	41.3	65.4	no sample	no sample	34.68333	21.24301
4 Water	no sample	63.8	70	27.8	43.7	56.53	44.33	no sample	56.35	65.25	no sample	no sample	53.47	14.01182
5 Water	no sample	71.6	63	17.2	68.9	21.3	171.5	no sample	107.4	135	no sample	no sample	84.4875	52.86695
6 Water	no sample	52	65.6	35.8	38.3	109	98.4	no sample	94.1	outlier	no sample	no sample	70.45714	30.06688
7 Water	no sample	52.6	48.8	no value	63.4	27.03	161.1	no sample	155	72.95	no sample	no sample	82.98286	53.22157
8 Water	no sample	70	69.4	78.5	68.1	28	99.6	no sample	107.2	outlier	no sample	no sample	74.4	25.70571
9 Water	no sample	38	17.8	9.9	no sample	121	191	no sample	110.5	135.6	no sample	no sample	89.11429	68.29955
I Water	no sample	52.85	outlier	23.1	50	18.45	55.1	33.6	24	48.75	35.85	no sample	37.96687	14.12748
II Water	no sample	55.85	outlier	8.65	2.8	10.7	15.4	35.35	11.9	51.85	38.2	no sample	25.61111	19.96243
III Water	no sample	67.8	37.7	7.4	3	11.5	16.5	32	12.05	48.8	39.05	no sample	27.38	20.7474
IV Water	no sample	57.75	72.6	21.9	14.2	36.5	47.25	60.95	26.8	67.4	37.25	no sample	44.26	20.07174
V Water	no sample	62.95	67.6	5.35	5.7	6.25	7.75	23.35	35.45	61.7	39.1	no sample	31.52	25.59345
VI Water	no sample	68.3	78.4	1.85	2.85	6	17.8	10.35	59	37.45	25.8	no sample	30.78	28.59296
VII Water	no sample	46.5	67.8	14.6	8.8	24.1	30.3	55.4	20.6	71.2	33.3	no sample	37.26	21.95289
VIII Water	no sample	50.8	outlier	15.05	30.7	11.35	17	25.55	14.8	49.9	40.2	no sample	28.37222	15.41306
IX Water	no sample	40.65	21.55	6.83	47.6	8.15	22.8	19.55	10.2	37.05	33.7	no sample	24.808	14.35952
I Water	no sample	42.35	45.95	8.2	no sample	50.45	60.2	no sample	23.45	45.85	35.7	no sample	39.01875	16.42437
II Water	no sample	47	60.25	8	no sample	29	40.85	no sample	26.35	38.05	31.5	no sample	35.125	15.47826
III Water	no sample	69.1	32.65	5.5	no sample	7.9	63.3	no sample	23.4	38.45	33.9	no sample	34.275	23.04452
IV Water	no sample	64.8	38.95	11.4	no sample	14.55	outlier	no sample	10.5	52.5	31.4	no sample	32.01429	21.35362
V Water	no sample	52.5	30.1	20.25	no sample	35	49.65	no sample	30	38.35	42.3	no sample	37.2675	10.76223
VI Water	no sample	26.95	54.8	30.5	no sample	56.3	outlier	no sample	34.56	53.45	51	no sample	43.93714	12.70348
VII Water	no sample	41.65	25.54	5.4	no sample	27.9	26.95	no sample	14.9	25.7	44.95	no sample	26.62375	12.83576
VIII Water	no sample	57.2	66.7	26.3	no sample	57.5	87.6	no sample	62.3	29.6	95.4	no sample	60.325	24.314

Table B-17 Sample BOD₅ Concentrations (2004)

Date	25-May-04	9-Jun-04	23-Jun-04	6-Jul-04	20-Jul-04	4-Aug-04	Average	Std. Dev
Lagoon	no eval	670.5	841.5	1086	1010	1090	939.6	181.00256
Exercise runoff	no eval	23.8	285	130.7	97.5	56.8	118.76	101.34931
Facultative Pond	no eval	38.6	42.6	104.8	85.9	100.47	74.474	31.736838
Cell 1 Influent	no eval	50.8	65.8	194	260	176	149.32	88.938136
Cell 2 Influent	no eval	48.75	59.5	37.55	53.9	54.05	50.75	8.3008283
Cell 3 Influent	no eval	17	10.5	47.1	55	125.9	51.1	45.927715
Cell 3 effluent	no eval	25	58.9	dry	41.4	89.2	53.625	27.460563
Filter Strip Runoff	no eval	10.8	18.9	dry	32.3	dry	20.666667	10.85833
1 _W	no sample	37.8	59.15	dry	tracer	68.8	55.25	15.863716
2 _W	no sample	34	45.1	dry	tracer	57.25	45.45	11.628951
3 _W	no sample	dry	dry	dry	tracer	66.6	66.6	#DIV/0!
4 _W	no sample	dry	56.55	dry	tracer	tracer	56.55	#DIV/0!
5 _W	no sample	36	38.15	53	tracer	tracer	42.383333	9.2569343
6 _W	no sample	56.2	54.5	33.2	tracer	tracer	47.966667	12.816526
7 _W	no sample	67.6	52.55	39.55	tracer	tracer	53.233333	14.03748
8 _W	no sample	60.8	58	29.85	tracer	tracer	49.55	17.118046
9 _W	no sample	56	42.3	46.45	tracer	tracer	48.25	7.0251335
1 _W	no sample	12.1	tracer	17.1	30.65	25.05	21.225	8.2410052
II _W	no sample	17.1	tracer	24.55	31.35	35	27	7.8937739
III _W	no sample	33	tracer	33.1	27.05	22.7	28.9625	5.0430439
IV _W	no sample	12.5	tracer	28	33.9	23.4	24.45	9.0518875
V _W	no sample	33.35	tracer	15.9	dry	23.65	24.3	8.7431402
VI _W	no sample	13.7	tracer	19.3	29.5	30	23.125	7.986812
VII _W	no sample	16.65	tracer	13.3	24.7	12.1	16.6875	5.6780829
VIII _W	no sample	dry	tracer	19.7	25.3	23.8	22.933333	2.8988503

Table B-18 Water Balance: June 2003

Max. Air Temp =	25 °C	
Min Air Temp =	9.5 °C	
Mean Air Temp =	17.7 °C	
	290.85 K	
Relative Humidity =	71.5 %	
Percent Sunshine =	60 %	
Wind Velocity =	0.35 m/s	
Vegetated Surface Wetland - Penman Equation for Evapotranspiration		
Sat. Water Pressure (Mean Temp) =	2.019761 kPa	
Actual Water Pressure =	1.444129 kPa	
Dew Point Temp. =	2.4 °C	
Sat. Water Pressure (Dew Point) =	0.727341 kPa	
Sat. Water Pressure (Max Temp) =	3.168781 kPa	
Sat. Water Pressure (Min Temp) =	1.184529 kPa	
Avg. Sat. Water Pressure =	2.176655 kPa	
Extraterrestrial Radiation =	35 MJ/m ² /d	Figure 9-3 Kadlec & Knight, 187
Solar Radiation =	19.25 MJ/m ² /d	
Net Long Wave Back Radiation =	4.972827 MJ/m ² /d	
Net Incoming Radiation =	9.849673 MJ/m ² /d	
Penman Factor =	0.636	
Evapotranspiration (depth) =	4.070609 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1353 m ²	
Evapotranspiration (volume) =	5.507534 m ³ /d	Assumption: uniformity of vegetation over the surface area of wetland
Cell 3		
Evapotranspiration (depth) =	4.070609 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1089 m ²	
Evapotranspiration (volume) =	4.432893 m ³ /d	Assumption: uniformity of vegetation over the surface area of wetland
Non-Vegetated Surface Wetland - Hamon Equation for Evaporation		
Avg No. of Daylight Hours/Day (Mean Temp) =	12 hr/d	
Sat. Water Pressure (Mean Temp) =	2.019761 kPa	
Mean Temp =	17.7 °C	
Facultative Pond		
Evaporation (depth) =	2.099607 mm/d	
Surface Area =	1914 m ²	
Evaporation (volume) =	4.018649 m ³ /d	
Cell 2		
Evaporation (depth) =	2.099607 mm/d	
Surface Area =	2178 m ²	
Evaporation (volume) =	4.572945 m ³ /d	

Table B-19 Water Balance: July 2003

Max. Air Temp =	26.6 °C	
Min Air Temp =	12.6 °C	
Mean Air Temp =	19.6 °C	
	292.75 K	
Relative Humidity =	66.5 %	
Percent Sunshine =	65 %	
Wind Velocity =	0.35 m/s	
Vegetated Surface Wetland - Penman Equation for Evapotranspiration		
Sat. Water Pressure (Mean Temp) =	2.275866 kPa	
Actual Water Pressure =	1.513451 kPa	
Dew Point Temp. =	2.4 °C	
Sat. Water Pressure (Dew Point) =	0.727341 kPa	
Sat. Water Pressure (Max Temp) =	3.487296 kPa	
Sat. Water Pressure (Min Temp) =	1.454534 kPa	
Avg. Sat. Water Pressure =	2.470915 kPa	
Extraterrestrial Radiation =	35 MJ/m ² /d	Figure 9-3 Kadlec & Knight, 187
Solar Radiation =	20.125 MJ/m ² /d	
Net Long Wave Back Radiation =	5.462925 MJ/m ² /d	
Net Incoming Radiation =	10.03332 MJ/m ² /d	
Penman Factor =	0.636	
Evapotranspiration (depth) =	4.426196 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1353 m ²	
Evapotranspiration (volume) =	5.988643 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Cell 3		
Evapotranspiration (depth) =	4.426196 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1089 m ²	
Evapotranspiration (volume) =	4.820127 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Non-Vegetated Surface Wetland - Hamon Equation for Evaporation		
Avg No. of Daylight Hours/Day (Mean Temp) =	13 hr/d	
Sat. Water Pressure (Mean Temp) =	2.275866 kPa	
Mean Temp =	19.6 °C	
Facultative Pond		
Evaporation (depth) =	2.758554 mm/d	
Surface Area =	1914 m ²	
Evaporation (volume) =	5.279873 m ³ /d	
Cell 2		
Evaporation (depth) =	2.758554 mm/d	
Surface Area =	2178 m ²	
Evaporation (volume) =	6.006131 m ³ /d	

Table B-20 Water Balance: August 2003

Max. Air Temp =	26.7 °C	
Min Air Temp =	13.3 °C	
Mean Air Temp =	19.9 °C	
	293.05 K	
Relative Humidity =	66 %	
Percent Sunshine =	65 %	
Wind Velocity =	0.35 m/s	
Vegetated Surface Wetland - Penman Equation for Evapotranspiration		
Sat. Water Pressure (Mean Temp.) =	2.318844 kPa	
Actual Water Pressure =	1.530437 kPa	
Dew Point Temp =	2.4 °C	
Sat. Water Pressure (Dew Point) =	0.727341 kPa	
Sat. Water Pressure (Max Temp.) =	3.508115 kPa	
Sat. Water Pressure (Min Temp.) =	1.522627 kPa	
Avg. Sat. Water Pressure =	2.515371 kPa	
Extraterrestrial Radiation =	35 MJ/m ² /d	Figure 9-3 Kadlec & Knight, 187
Solar Radiation =	20.125 MJ/m ² /d	
Net Long Wave Back Radiation =	5.485353 MJ/m ² /d	
Net Incoming Radiation =	10.0109 MJ/m ² /d	
Penman Factor =	0.636	
Evapotranspiration (depth) =	4.466909 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1353 m ²	
Evapotranspiration (volume) =	6.043728 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Cell 3		
Evapotranspiration (depth) =	4.466909 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1069 m ²	
Evapotranspiration (volume) =	4.864464 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Non-Vegetated Surface Wetland - Hamon Equation for Evaporation		
Avg No. of Daylight Hours/Day (Mean Temp.) =	12 hr/d	
Sat. Water Pressure (Mean Temp.) =	2.318844 kPa	
Mean Temp =	19.9 °C	
Facultative Pond		
Evaporation (depth) =	2.39242 mm/d	
Surface Area =	1914 m ²	
Evaporation (volume) =	4.579092 m ³ /d	
Cell 2		
Evaporation (depth) =	2.39242 mm/d	
Surface Area =	2178 m ²	
Evaporation (volume) =	5.210991 m ³ /d	

Table B-21 Water Balance: September 2003

Max. Air Temp =	22.8 °C	
Min Air Temp =	8.5 °C	
Mean Air Temp =	15.7 °C	
	286.85 K	
Relative Humidity =	62.7 %	
Percent Sunshine =	60 %	
Wind Velocity =	1.8 m/s	
Vegetated Surface Wetland - Penman Equation for Evapotranspiration		
Sat. Water Pressure (Mean Temp.) =	1.77823 kPa	
Actual Water Pressure =	1.11495 kPa	
Dew Point Temp =	2.4 °C	
Sat. Water Pressure (Dew Point) =	0.727341 kPa	
Sat. Water Pressure (Max Temp.) =	2.77308 kPa	
Sat. Water Pressure (Min Temp.) =	1.10754 kPa	
Avg. Sat. Water Pressure =	1.94031 kPa	
Extraterrestrial Radiation =	35 MJ/m ² /d	Figure 9-3 Kadlec & Knight, 187
Solar Radiation =	19.25 MJ/m ² /d	
Net Long Wave Back Radiation =	4.837451 MJ/m ² /d	
Net Incoming Radiation =	9.985049 MJ/m ² /d	
Penman Factor =	0.636	
Evapotranspiration (depth) =	5.52348 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1353 m ²	
Evapotranspiration (volume) =	7.473241 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Cell 3		
Evapotranspiration (depth) =	5.52348 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1069 m ²	
Evapotranspiration (volume) =	6.015048 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Non-Vegetated Surface Wetland - Hamon Equation for Evaporation		
Avg No. of Daylight Hours/Day (Mean Temp.) =	11 hr/d	
Sat. Water Pressure (Mean Temp.) =	1.77823 kPa	
Mean Temp =	15.7 °C	
Facultative Pond		
Evaporation (depth) =	1.56403 mm/d	
Surface Area =	1914 m ²	
Evaporation (volume) =	2.993553 m ³ /d	
Cell 2		
Evaporation (depth) =	1.56403 mm/d	
Surface Area =	2178 m ²	
Evaporation (volume) =	3.408458 m ³ /d	

Table B-22 Water Balance: October 2003

Max. Air Temp =	11.8 °C	
Min Air Temp =	-1 °C	
Mean Air Temp =	5.8 °C	
"	278.95 K	
Relative Humidity =	70.6 %	
Percent Sunshine =	45 %	
Wind Velocity =	2.3 m/s	
Vegetated Surface Wetland - Penman Equation for Evapotranspiration		
Sat. Water Pressure (Mean Temp.) =	0.921536 kPa	
Actual Water Pressure =	0.650604 kPa	
Dew Point Temp. =	2.4 °C	
Sat. Water Pressure (Dew Point) =	0.727341 kPa	
Sat. Water Pressure (Max Temp.) =	1.380053 kPa	
Sat. Water Pressure (Min Temp.) =	0.570684 kPa	
Avg Sat. Water Pressure =	0.975369 kPa	
Extraterrestrial Radiation =	35 MJ/m ² /d	Figure 9-3 Kadlec & Knight, 187
Solar Radiation =	16.625 MJ/m ² /d	
Net Long Wave Back Radiation =	3.320045 MJ/m ² /d	
Net Incoming Radiation =	9.481205 MJ/m ² /d	
Penman Factor =	0.636	
Cell 1		
Evapotranspiration (depth) =	3.175705 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1353 m ²	
Evapotranspiration (volume) =	4.296729 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Cell 2		
Evapotranspiration (depth) =	3.175705 mm/d	Assumption: no conductive heat losses to ground
Surface Area =	1089 m ²	
Evapotranspiration (volume) =	3.458343 m ³ /d	Assumption: assuming uniformity over the surface area of the wetland
Non-Vegetated Surface Wetland - Hamon Equation for Evaporation		
Avg No. of Daylight Hours/Day (Mean Temp.) =	10 hr/d	
Sat. Water Pressure (Mean Temp.) =	0.921536 kPa	
Mean Temp =	5.8 °C	
Facultative Pond		
Evaporation (depth) =	0.693829 mm/d	
Surface Area =	1914 m ²	
Evaporation (volume) =	1.327606 m ³ /d	
Cell 2		
Evaporation (depth) =	0.693829 mm/d	
Surface Area =	2178 m ²	
Evaporation (volume) =	1.510725 m ³ /d	

APPENDIX C
TRACER CONCENTRAION DATA

Table C-1 Tracer Concentration Data

Site background Day	Cell 1 (2003)									Cell 1 (2004)									Cell 3 (2003)								
	5	6	7	8	9	1	2	3	4	5	6	7	8	9	i	ii	v	vi	vii	viii							
	15	15	15	15	15	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	18	18	18	18	18	18							
1	0.85	0	0	3.01	0	0.00	1.06	11.26	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	88.44							
2	5.33	3.91	2.03	0	0	0.00	146.40	48.34	0.00	0.00	0.00	0.00	0.00	0.00	0	0	7.62	0	21.42	33.78							
3	0	3.91	2.74	0	0	0.00	222.56	81.15	0.00	0.00	0.00	0.00	0.00	0.00	0	0	19.22	0	23.71	13.2							
4	9.43	1.23	0	0	16.48	0.00	151.02	135.65	0.00	0.00	0.00	0.00	0.00	0.00	0	0	2.73	23.71	0	17.1							
5	48.64	3.84	6.54	6.88	2.38	6.05	137.99	105.46	0.00	0.00	0.00	0.00	0.00	0.00	2.74	4.3	16.32	0	21.42	8.76							
6	8.09	55.75	49.85	10.96	5.22	0.00	60.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	3.31	20.53	0	5.4							
7	7.62	34.49	12.24	11.25	3.81	0.00	0.00	64.63	0.00	0.00	0.00	0.00	0.00	0.00	0	0	12.47	0	3.8	0							
8	7.89	17.83	8.47	1.82	7.86	0.00	8.57	74.66	0.00	55.40	0.00	3.85	19.27	1.64	0	0	16.31	3.89	3.61	0							
9	5.28	11.65	10.01	11.85	3.81	31.94	39.11	74.66	13.70	69.54	16.43	28.57	19.27	0.00	0	0	3.8	22.77	0	7.05							
10	6.25	7.86	11.25	7.1	8.75	55.40	42.93	8.71	16.43	27.01	19.27	3.63	28.57	0.00	0	0	18.39	8.77	5.39	0							
11	10.64	4.05	59.46	7.45	10.55	3.63	0.00	19.02	0.00	44.05	0.00	22.14	0.00	0.00	0.79	3.8	15.15	10.55	0.78	0							
12	20.79	9.25	12.01	14.15	17.13	19.02	5.34	38.25	0.00	68.79	13.19	50.23	13.19	15.55	0	0	7.65	7.05	0	0							
13	8.42	6.93	29.54	26.11	1.93	34.58	15.55	8.20	12.83	42.53	38.25	34.33	34.58	0.00	0	0	7.39	2.04	0	0							
14	10.18	3.87	4.56	0	19.16	16.88	0.00	4.02	34.33	26.47	20.06	23.22	23.38	0.00	0	0	1.65	0	0	0							
15	33.38	12.05	18.02	25.99	0	8.92	0.00	0.00	0.00	37.11	6.42	40.98	4.02	0.00	0	0	15.86	0	1.8	0							
16	23.6	56.5	24.63	23.6	19.61	0.00	0.00	0.00	0.00	37.11	6.42	53.65	11.54	0.00	0	0	0	0	3.31	0							
17	37.8	0	26.51	20.86	0	0.00	0.00	0.00	0.00	36.75	17.12	36.75	11.52	0.00	0	0	0	0	0	0							
18	0	6.08	0	22.28	0	0.00	0.00	0.00	0.00	29.61	23.06	0.00	29.61	0.00	0	0	4.34	0	0	0							
19	0	0	0	0	0	0.00	0.00	0.00	0.00	15.89	17.04	10.58	5.69	0.00	0	0	0	0	0	0							
20						0.00	0.00	0.00	0.00	10.63	0.00	10.63	8.08	0.00	0	0	0	0	0	0							
21						0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.87	0.00	0	0	0	0	0	0							
22						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0							
23						0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.23	0.00	0	0	0	0	0	0							
24						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0							
25						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0							
26						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0							

APPENDIX D
MODEL CALCULATIONS AND RESIDENCE TIME
DISTRIBUTIONS

Table D-1 Model Calculations (2003)

Site	Flow (m ³)		Ammonia		Nitrates		TKN		TP		TSS		BOD ₅		Volumes (m ³)	
	in	out	in	out	in	out	in	out	in	out	in	out	in	out	Design	Tracer
Cell 1	3350.7	3072.45	73.92	21.9	3.51	1.32	88.39	53.8	47.7	28.35	483.18	460	299.87	115.2	405.9	306.6
Cell 2	3072.45	3492.49	21.9	10.02	1.32	1.43	53.8	24.57	28.35	21.052	460	75	115.2	76.6	2178	2178
Cell 3	3492.49	3268.53	10.02	3.17	1.43	1.43	24.57	18.3	21.052	18.2836	75	148	76.6	72.4	326.7	242.44

r	Kadlec and Knight		Reed et al.	
	$\tau = Q/A$ (m/yr)	Design Tracer	$\tau = Q/\epsilon Ah$ (yr ⁻¹)	Design Tracer
Cell 1	5.662678	7.496674	19.86904	26.30412
Cell 2	1.078613	1.078613	3.784608	3.784608
Cell 3	7.405524	9.979313	25.98429	35.01513
wetland	0.8138	0.868578	2.855438	3.047641

Background calculations	from CH2M Hill (m/yr)	3		0		10		2		20		8	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
Cell 1	Kadlec and Knight	7.486269	9.91353	5.538008	7.331629	3.296032	4.363533	3.118039	4.127894	0.040779	0.05279	5.667924	7.503621
Cell 2	Model $k = -\ln((C-C_0)/(C-C_0)) \cdot \tau$	1.068257	1.068257	-0.086335	-0.086335	1.187196	1.187196	0.34979	0.34979	2.086965	2.086965	0.481497	0.481497
Cell 3		27.55388	37.13023	0	0	4.167156	5.61545	1.162788	1.566888	-5.57537	-7.513089	0.467873	0.630482
wetland		4.910069	5.240571	#NUM!	#NUM!	1.399228	1.493412	0.873364	0.932152	0.939844	1.003106	1.182234	1.261812
assumed values		10		14		8		21		22			
Percent difference	cell 1	25.11731	0.864695	#DIV/0!	#DIV/0!	76.45692	68.83191	61.02451	48.40133	99.80582	99.74862	74.23671	65.89263
	cell 3	-175.5388	-271.3023	#DIV/0!	#DIV/0!	70.2346	59.88964	85.4654	80.4139	126.5494	135.7766	97.87331	97.13417

calculations	(yr ⁻¹)	k		k		k		k		k		k	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
Cell 1	Reed et al. Model $k = \ln(C/C_0) \cdot \tau$	24.17062	31.99888	19.43161	25.72501	9.864687	13.05981	2.946315	3.900552	0.136883	0.181216	18.99504	25.14706
Cell 2		2.959197	2.959197	-0.30293	-0.30293	2.968175	2.968175	0.321029	0.321029	8.864286	8.864286	1.544394	1.544394
Cell 3		29.90406	40.29722	0	0	7.655626	10.31634	1.044113	1.406994	-17.66215	-23.80063	1.465275	1.974531
wetland		8.992494	9.597789	2.564017	2.736604	4.496909	4.799601	2.738157	2.922465	3.257779	3.477064	4.05608	4.329099
assumed values		80		96		96		248					
Percent difference	cell 1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	67.68914	83.67549	70.41852	60.83783	#DIV/0!	#DIV/0!	92.34071	89.68006
	cell 3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	90.43047	87.10458	89.51894	85.87355	#DIV/0!	#DIV/0!	99.40916	99.20382

calculations	(yr ⁻¹)	k		k		k		k		k		k	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
Cell 1	Cstr Equations $k = ((C/C_0) - 1) / (Q/V)$	42.89369	56.78588	29.9597	39.66288	11.61009	15.3703	12.32523	16.31706	0.124835	0.165266	28.91815	38.28136
Cell 2		4.535524	4.535524	-0.294263	-0.294263	4.550953	4.550953	1.32614	1.32614	19.63714	19.63714	1.92769	1.92769
Cell 3		51.57463	69.49938	0	0	8.177513	11.01981	3.613865	4.869863	-11.77242	-15.86393	1.384572	1.86578
wetland		-2.596336	-2.771098	-1.607506	-1.715709	-2.151044	-2.295833	-1.672891	-1.785495	-1.845888	-1.970136	-2.057289	-2.195767

calculations	(d ⁻¹)	k		k		k		k		k		k	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
Cell 1	crites and Tchobanoglous $k = ((1/(C/C_0)) * (1/m)) - 1) * ((n*Q)/V)$	11.24921	14.89255	8.766046	11.60515	4.182508	5.537117	4.396512	5.820432	0.054556	0.072226	8.544653	11.31205
Cell 2		1.301471	1.301471	-0.119434	-0.119434	1.30485	1.30485	0.465671	0.465671	3.458548	3.458548	0.647473	0.647473
Cell 3		13.79829	18.59389	0	0	3.1637	4.263244	1.484914	2.000995	-6.46827	-8.716317	0.587633	0.791865
wetland		5.446589	5.813204	1.144724	1.221777	2.19448	2.342193	1.232188	1.315128	1.501243	1.602293	1.939195	2.069724

Table D-2 Model Calculations (2004)

Site	Flow (m ³)		Ammonia		Nitrates		TKN		TP		TSS		BOD ₅		Volumes (m ³)	
	in	out	in	out	in	out	in	out	in	out	in	out	in	out	Design	Tracer
Cell 1	3350.7	3072.45	13.3555	10.4206	1.025167	1.074833	48.26	41.74	16.741	11.38217	275.439	46.152	149.32	50.75	405.9	271.7
Cell 2	3072.45	3492.49	10.4206	7.1464	1.074833	1.069687	41.74	21.053	11.38217	11.4315	46.152	442.9583	50.75	51.1	2178	2178
Cell 3	3492.49	3268.53	7.1464	2.10775	1.069687	1.126	21.053	28.277	11.4315	11.0248	442.9583	76.686	51.1	53.625	326.7	242.44

τ	Kadlec and Knight		Reed et al.	
	$\tau = Q/A$ (m/yr)		$\tau = Q/cAh$ (yr ⁻¹)	
	Design	Tracer	Design	Tracer
Cell 1	5.662678	8.459625	19.86904	29.6829
Cell 2	1.078613	1.078613	3.784606	3.784606
Cell 3	7.405524	9.979313	25.96429	35.01513
wetland	0.8138	0.879838	2.855438	3.08715

Background calculation	from CH2M Hill (m/yr)	3		10		2		20		8	
		k		k		k		k		k	
cell 1	Kadlec and Knight Model $k = -\ln((c-c^*)/(c^*-c^*)) \cdot i$	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
		1.887131	2.819237	-0.267904	-0.400228	1.057942	1.580488	2.558522	3.822245	12.90557	16.88556
		0.827774	0.627774	0.005197	0.005197	1.137803	1.137803	-0.005657	-0.005657	-9.398834	-9.398834
		#NUM!	#NUM!	-0.380084	-0.512183	-3.724546	-5.019011	0.326427	0.439876	48.60743	65.50093
cell 2											
cell 3											
wetland											
assumed values		10		14		8		21		22	
Percent difference	cell 1	81.12669	71.60763	#DIV/0!	#DIV/0!	92.44327	88.7108	68.01848	52.22194	38.54492	19.68783
	cell 3	#NUM!	#NUM!	#DIV/0!	#DIV/0!	126.6039	135.8501	95.91967	94.50155	-131.4639	-211.9092

calculation	(yr ⁻¹)	k		k		k		k		k		k	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
cell 1	Reed et al. Model $k = \ln(c/c_0) \cdot i$	4.930378	7.365623	-0.940012	-1.40431	2.883855	4.308289	2.184734	3.263833	35.49456	53.02629	21.44227	32.03319
cell 2		1.427462	1.427462	0.018236	0.018236	2.590248	2.590248	-0.004665	-0.004665	-8.559021	-8.559021	-0.026011	-0.026011
cell 3		31.7265	42.75305	-1.33363	-1.797133	-7.665514	-10.32968	0.268268	0.361505	45.57013	61.40802	-1.253245	-1.688811
wetland		5.272016	5.699627	-0.267887	-0.289625	1.526387	1.650249	1.192755	1.289544	3.651098	3.947375	2.924187	3.161477
assumed values				80		9.96						248	
Percent difference	cell 1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	96.39518	94.61466	78.06492	67.23059	#DIV/0!	#DIV/0!	91.35392	87.08339
	cell 3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	109.5819	112.9121	97.30654	96.37043	#DIV/0!	#DIV/0!	100.5053	100.681

calculation	(yr ⁻¹)	k		k		k		k		k		k	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
cell 1	Cstr Equations $k = ((c/c^*) - 1) \cdot (Q/V)$	5.0859	7.597963	-0.834432	-1.248581	2.820735	4.213973	8.501832	12.70112	89.71315	134.0249	35.07324	52.39687
cell 2		1.752656	1.752656	0.018477	0.018477	3.758913	3.758913	-0.016509	-0.016509	-3.426845	-3.426845	-0.026201	-0.026201
cell 3		57.05581	76.88555	-1.194078	-1.609077	-6.097483	-8.216636	0.880457	1.18646	113.9968	153.6164	-1.123825	-1.514411
wetland		-2.284556	-2.469942	0.266812	0.288464	-1.123233	-1.21438	-0.926238	-1.001399	-1.957423	-2.116262	-1.738472	-1.879544

calculation	(d ⁻¹)	k		k		k		k		k		k	
		Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer	Design	Tracer
cell 1	crites and Ichobanoglous $k = ((1/(c/c^*)) \cdot (1/n)) \cdot i \cdot ((n^2 \cdot Q)/V)$	2.025549	3.026023	0.372126	0.555929	1.169498	1.747142	3.20471	4.787803	17.81832	26.61927	9.801545	14.64279
cell 2		0.596106	0.596106	0.007266	0.007266	1.124988	1.124988	-0.006515	-0.006515	-2.803418	-2.803418	-0.010349	-0.010349
cell 3		14.7745	19.90937	-0.527684	-0.711081	-2.942707	-3.965444	0.376543	0.507411	22.7762	30.69206	-0.49607	-0.668479
wetland		2.667949	2.884446	-0.105436	-0.113992	0.650323	0.703095	0.500665	0.541293	1.713195	1.852216	1.327109	1.4348

Figure D-1 TP Concentrations and Model Predictions in FWS #1 (2003)

Figure D-2 TKN Concentrations and Model Predictions in FWS #1 (2003)

Figure D-3 BOD₅ Concentrations and Model Predictions in FWS #1 (2003)

Figure D-4 TP Concentrations and Model Predictions in FWS #1 (2004)

Figure D-5 BOD₅ Concentrations and Model Predictions in FWS #1 (2004)

Figure D-6 TP Concentrations and Model Predictions in FWS #2 (2003)

Figure D-7 TKN Concentrations and Model Predictions in FWS #2 (2003)

Figure D-8 BOD₅ Concentrations and Model Predictions in FWS #2 (2003)

Figure D-9 TP Concentrations and Model Predictions in FWS #2 (2004)

Figure D-10 BOD₅ Concentrations and Model Predictions in FWS #2 (2004)

Figure D-11 Ammonia Concentrations and Model Predictions in FWS #2 (2004)